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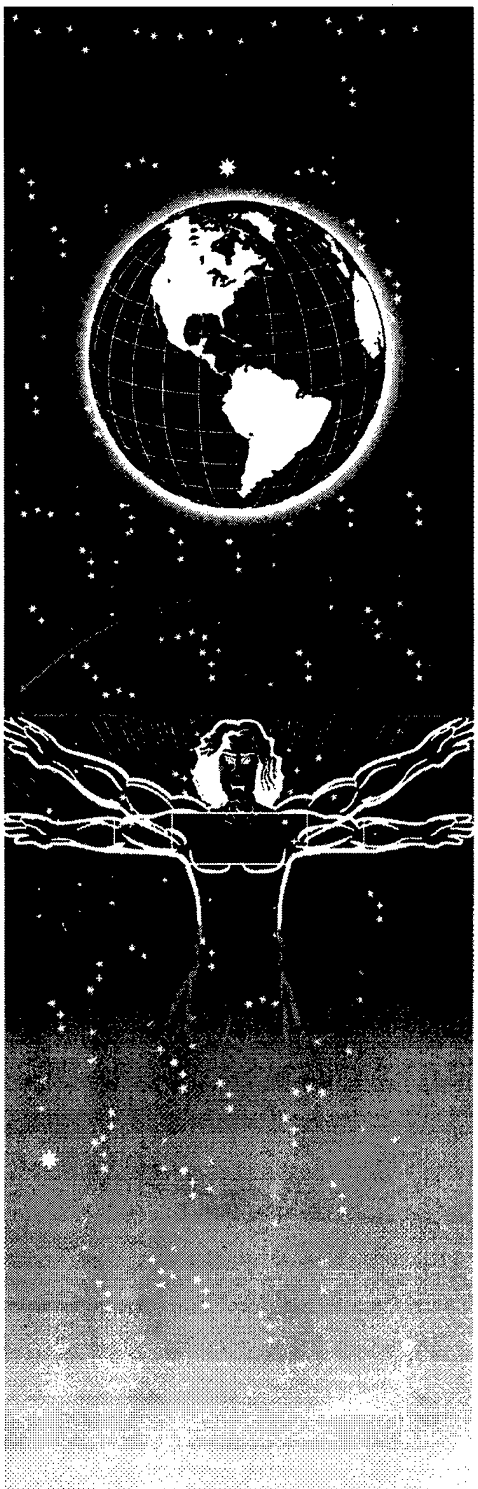

UNITED STATES AIR FORCE
ARMSTRONG LABORATORY

Control Technology for Depainting Operations: Estimation of Life-Cycle Costs of Controlling Methylene Chloride in Aircraft-Depainting Operations Versus Alternative Processes

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13. ABSTRACT *(Maximum 200 words)*
Stripping the paint and other coatings from aircraft frames using chemical stripper formulations based on methylene chloride (MC) has been a standard practice at Air Logistics Centers (ALCs) for more than 50 years. The U.S. Environmental Protection Agency (EPA) has recently listed MC as a hazardous air pollutant and has subsequently issued National Emissions Standards for Hazardous Air Pollutants (NESHAPs) for major source categories. EPA specifically promulgated MC NESHAPs for Aerospace Manufacturing and Rework Facilities in September 1995. These standards will require paint stripping facilities that continue to use MC to implement MC emission controls that are at least 95-percent efficient by 1 September 1998. This report discusses the technical feasibility and costs of replacing current MC-stripping operations at ALCs with alternative stripping processses, discusses various MC-control technologies and control strategies that could be applied to current MC-stripping operations at ALCs, and estimates the life-cycle costs of selected alternative processes and MC-control strategies. These estimated life-cycle costs, and the procedures used to derive them, can be used by depainting facility managers to support informed decisions in their selection of NESHAP compliance approaches.

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PREFACE

This report was prepared by Acurex Environmental Corporation, 555 Clyde Avenue, Mountain View, CA 94043 under Contract F08637-95-D6003, Delivery Order 5303, for the U.S. Air Force Armstrong Laboratory/Environics Directorate (AL/EQ), 139 Barnes Drive, Tyndall AFB, FL 32403-5323.

This technical report summarizes work performed between 30 July 1996 and 1 May 1997. The AL/EQ Program Manager was Dr. Joseph D. Wander.

Data cited in this report associated with commercial products are included for illustrative purposes only, and are not to be considered as an evaluation or product endorsement. All mention of trade names or commercial products does not constitute endorsement or recommendation for use.

List of mentioned trademarks

Aqua Miser
Cadre
CEE-BEE A-458
CEE-BEE R-256
DOWEX OPTIPORE V502
Dry Ice
FLASHJET
FluiSorb
Koroflex
MAG 10000
Neoprene
PR 3140
PR 3500-19
PR 5000
Turco 6776

EXECUTIVE SUMMARY

A. OBJECTIVE

The objective of this project, initiated under Air Force (AF) Armstrong Laboratory contract F08637-95-D6003/DO5303, was to identify and estimate the life-cycle costs of controlling methylene chloride (MC) in aircraft-depainting operations, and to compare these costs to the costs of alternative stripping methods.

B. BACKGROUND

Depainting an aircraft frame is an essential, recurring maintenance item during the frame's life cycle. The AF depainting operations have used MC as their primary chemical stripper for more than 50 years. Recently, MC has been categorized as a highly toxic substance, subject to regulation by the U.S. Environmental Protection Agency (EPA) as a hazardous air pollutant (HAP).

Containment and control of MC emissions to the National Emission Standard for Hazardous Air Pollutants (NESHAP)-mandated 95-percent reduction is technically feasible. Whether containment/control or the use of alternative technology to replace MC is the best strategy to adopt will depend on site-specific depainting requirements and existing conditions at each of the AF's depainting facilities.

C. SCOPE

This report provides an overview of aircraft-depainting activities in the AF; a description of various existing and emerging methods; a discussion of the main elements of each depainting method; and a summary of the aerospace rework NESHAP and selected regional and site-specific regulations. A rough order of magnitude cost analysis was performed for five depainting methods. Strategies for the containment/control of MC were discussed, along with implementing plans and costs.

D. CONCLUSIONS

These results suggest that the most cost-effective NESHAP compliance strategy will be to eliminate MC-based stripping within the AF and adopt one or more alternative processes. However, this presupposes that all options depaint an equivalent surface, induce the same susceptibility to corrosion, and include the same costs to attend to peripheral effects.

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GLOSSARY OF TERMS

ACGIH	American Conference of Governmental Industrial Hygienists
AF	U.S. Air Force
AFB	Air Force base
AFOSH	Air Force Office of Safety and Health
ALCs	U.S. Air Force Air Logistics Centers
AOC	Annual operating cost
BA	Benzyl alcohol
BOS	Bicarbonate of soda
CI	Capital investment
DBE	Dibasic esters
DF	Discount factor
DoD	U.S. Department of Defense
EPA	U.S. Environmental Protection Agency
HAP	Hazardous air pollutant
HTO	Hydrothermal oxidation
HVAC	Heating, ventilation, and air conditioning
IWTP	Industrial wastewater treatment plant
LARPS	Large-area robotic paint stripping
LARPS/HPW	Large-area robotic paint stripping with high-pressure water blasting
LEL	Lower explosive limit
MACT	Maximum Achievable Control Technology
MC	Methylene chloride
MEK	Methyl ethyl ketone
MPW/BOSS	Medium-pressure water/bicarbonate-of-soda stripping
NADEP	Naval Aviation Depot
NDCEE	National Defense Center for Environmental Excellence
NESHAP	National Emission Standard for Hazardous Air Pollutants
NMP	*N*-methyl-2-pyrrolidone
N/P	Not present
OAQPS	U.S. EPA's Office of Air Quality Planning and Standards
OSHA	Occupational Safety and Health Administration
OTL	One-sided tolerance limit
PEL	Permissible exposure limit
PMB	Plastic-media blasting
PPE	Personal protective equipment
RACT	Reasonably Available Control Technology
ROM	Rough order-of-magnitude
RTO	Regenerative thermal oxidizer
SCWO	Supercritical water oxidation
STEL	Short-term exposure limit
SVOC	Semivolatile organic compound
TLV	Threshold limit value
TPV	Total present value
TWA	Time-weighted average
UAC	Uniform annual cost
UV	Ultraviolet
VOC	Volatile organic compound

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SECTION I
INTRODUCTION

A. OBJECTIVE

The overall objective of this project was to define the primary cost factors, estimate their respective amounts, and display and interpret these in a form that provides guidance in the evaluation of options to organizations faced with installing a new depainting facility, or with a choice to control emissions from or to convert the process used in an existing depainting facility. The result is aimed at providing a procedure for estimating the economic consequences of either continuing to operate an existing MC facility with add-on emission controls, or converting the facility to implement an alternative depainting process.

B. BACKGROUND

Depainting an aircraft frame is an essential, recurring maintenance item during its life cycle. One common method of depainting, or paint stripping, in the aircraft rework industry has been based on the use of methylene chloride (MC) as a solvent. U.S. Air Force (AF) depainting operations have used MC as their primary chemical stripper for more than 50 years. Recently, however, MC has been categorized as a highly toxic substance, subject to regulation by the U.S. Environmental Protection Agency (EPA) as a hazardous air pollutant (HAP). The AF has responded with strenuous efforts to phase MC out of all nonessential uses. For continuing applications, the National Emission Standard for Hazardous Air Pollutants (NESHAP) for Aerospace Manufacturing and Rework Facilities (aerospace rework NESHAP) requires 95-percent reduction in emissions of MC from depainting facilities through the use of the Maximum Achievable Control Technology (MACT) standards by September 1998. Progressively increasing restrictions on the emissions of volatile organic compounds (VOCs) and HAPs are perceived as a tactical approach to enforce implementation of alternatives to MC-based stripping. In this environment, the need to evaluate technical and economic aspects both of paint removal technologies (and their respective consequences to the aircraft's life cycle) and of affordable control of MC emissions from aircraft rework facilities is urgent.

Containment and control of MC emissions is technically feasible. Whether containment/control or the use of alternative technology to replace MC is the best strategy to adopt will depend on the site-specific depainting requirements and existing conditions at each of the AF's depainting facilities. Local, case-by-case decisions are expected to be facilitated by the availability of a reference data base that summarizes the following:

- The feasibility of implementing an alternative paint stripping process
- The compatibility of aircraft frames with alternative stripping processes and the quality afforded by the alternative processes
- The cost of alternative control/containment technology options
- Other locally determined impacts caused by a change in the depainting process

This project was initiated by the AF Armstrong Laboratory under Contract F08637-95-D6003/DO5303 to identify and estimate the life-cycle costs of controlling MC in aircraft-depainting operations, and to compare these costs to the costs of alternative stripping methods.

C. SCOPE

The report is organized into seven sections. Section II provides background information on AF depainting facilities and discusses various depainting-process options. The section gives

- An overview of aircraft-depainting activities in the AF
- A description of various existing and emerging depainting methods
- A discussion of the main elements of each depainting method that includes
    - Workload capabilities
    - Material usage
    - Production rates
- A summary of the aerospace rework NESHAP and selected regional and site-specific regulations related to the Occupational Safety and Health Administration (OSHA), and to HAP and VOC emissions

Section III presents a rough order-of-magnitude (ROM) cost analysis for the use of five of the depainting methods discussed in Section II:

- MC
- Benzyl alcohol
- Benzyl alcohol with medium-pressure water/bicarbonate-of-soda stripping (MPW/BOSS)
- Large-area robotic paint stripping (LARPS) using high-pressure water
- Laser stripping

The estimated process-operating costs for each method are normalized to a unit stripping rate to allow cost comparisons among processes on a common basis.

Section IV discusses various strategies for the control/containment of MC. From the various options described, selected cost-effective strategies are outlined.

Section V discusses conceptual plans and preliminary cost estimates for implementing the strategies discussed in Section IV in a specific application — the conversion or control of the Building 2122 facility at Tinker AFB, Oklahoma.

Section VI compares the estimated life-cycle costs of controlling MC using various approaches to the costs of implementing the alternative stripping methods discussed in Section III.

Section VII summarizes study conclusions.

A list of references is given at the end of each section.

Finally, the appendices contain all associated calculation spreadsheets, stripping solvent/formulation material safety data sheets (MSDSs), and copies of responses to questionnaires.

SECTION II

FACILITY ANALYSIS AND DEPAINTING TECHNOLOGY ALTERNATIVES

A. DEPAINTING METHODS USED AT AIR LOGISTICS CENTERS

Aircraft-frame depainting is performed at the five AF Air Logistics Centers (ALCs): OC-ALC at Tinker AFB; WR-ALC at Robins AFB; OO-ALC at Hill AFB; SA-ALC at Kelly AFB; and SM-ALC at McClellan AFB. Information on the depainting process used at each ALC was obtained through telephone interviews with, and questionnaire responses from, the engineering and environmental management staff and their support contractors at the five ALCs. Data gathered through the interviews and questionnaires were also supplemented by a review of technical literature and a survey of online electronic data bases. In addition to the ALCs, two Naval Aviation Depots (NADEPs) were contacted for depainting process information. A list of references that supplied data is included at the end of this section.

Table 1 lists the aircraft-depainting processes used at the various ALCs during 1995. Because of the incoming aerospace rework NESHAP (1, 2) and recent changes to the OSHA regulations, there is a drive within the AF to eliminate MC as a stripping solvent. Despite this, the general opinion of the various ALC and commercial depainting process operators is that MC is the best paint-stripping agent available for metallic surfaces, although this may be due to the high level of comfort resulting from the experience accumulated during the use of MC for over 50 years.

B. EXISTING DEPAINTING PROCESSES USED AT ALC FACILITIES

1. Methylene Chloride Stripping

For more than 50 years, MC has been the workhorse paint stripper used in the aerospace industry for the rapid and efficient removal of paint coatings. However, during the 1970s, the potential environmental and health risks associated with the use of chemical strippers became recognized. EPA has now established regulations limiting emissions of 189 HAPs from specific source categories. These HAPs have been characterized as being carcinogenic, mutagenic, bioaccumulative, or capable of causing other adverse effects. Accordingly, EPA recently proposed HAP regulations in the form of the aerospace rework NESHAP for aircraft painting and depainting operations. MC is one of these HAPs. In addition to the proposed NESHAP, chemical stripping operations in the AF, including MC stripping, are required to meet both OSHA and Air Force Office of Safety and Health (AFOSH) standards to protect worker safety.

TABLE 1. ALC AIRCRAFT DEPAINTING PROCESSES IN USE IN 1995 (1).

Site	Aircraft Type	Primary Depainting Methods
OC-ALC	B-1	MC stripping[a]
	B-52	MC stripping
	KC-135	MC stripping
	E-3	MC stripping
WR-ALC	C-130	MPW/BOSS[b] — Aqua Miser™
	C-141	Plastic media blasting
	F-15	MPW/BOSS — Aqua Miser™
SA-ALC	A-10	PMB[c]/sand scuffing
	C-130	PMB
	C-5	PMB, MC stripping for spot depainting
SM-ALC	A-10	PMB
	KC-135	MC stripping
	F-15	PMB
OO-ALC	C-130	MPW/BOSS — Aqua Miser™
	F-16	PMB/sand scuffing

[a]MC = Methylene chloride.
[b]MPW/BOSS = medium-pressure water/bicarbonate of soda stripping.
[c]PMB = Plastic media blasting.

Chemical stripping involves the use of one or more potentially hazardous materials either individually, such as 2-butanone (methyl ethyl ketone [MEK]), or in combinations containing MC, phenols, or formic acid. Sometimes these stripping solutions contain toxic metals such as chromium. Acid strippers (MC + formic acid) are not authorized for use on AF equipment due to the potential for hydrogen embrittlement in low-alloy, high-strength steels. The composition of three commercial MC-based strippers used by the AF for aircraft frame depainting, and the allowable exposure levels for their HAP constituents, are listed (3) in Table 2. The guidance on the selection of strippers and corresponding commercial vendors is provided (4) in the AF document TO 1-1-8.

Currently two ALCs, OC-ALC and SM-ALC, use MC to strip entire aircraft frames. MC is used at OC-ALC to strip KC-135, E-3, B-1, and B-52 aircraft. At SM-ALC only KC-135 aircraft are stripped using MC, with this activity under the management of the OC-ALC weapon systems manager. These AF depainting facilities are opting to eliminate MC stripping in the future, as they are under pressure to comply with the impending NESHAP, which requires reduction of HAP emissions by 95 percent.

TABLE 2. COMPOSITION OF MC-BASED STRIPPERS IN AF USE AND OCCUPATIONAL EXPOSURE LIMITS FOR THEIR CONSTITUENTS.

HAP Component	Product Composition, wt%			Occupational Exposure Limit, ppm[a]	
	CEE-BEE A-458™	CEE-BEE R-256™	El Dorado PR-3500-19™	OSHA PEL	ACGIH TLV
Methylene chloride	81	48.5	50	25	50[b]
Phenol	N/P[c]	9.7	20	5	5
Chromium[d]	N/P	0.2	0.8	0.1 mg/m^3	0.05 mg/m^3
Toluene	N/P	1.4	N/P	100	50
Methanol	N/P	N/P	N/P	200	200
Cresol	N/P	N/P	N/P	5	5
Product bulk density, lb/gal	10	10	10		

[a]OSHA = Occupational Safety and Health Administration, PEL = permissible exposure limit, ACGIH = American Conference of Governmental Industrial Hygienists, TLV = threshold limit value.
[b]Subject to change due to recent OSHA regulations.
[c]N/P = Not present in this formulation.
[d]= As sodium chromate.

a. **Description of MC-Based Facilities and Their Operation**[1,2,3,4]

At both OC-ALC and SM-ALC the KC-135s, and at OC-ALC the B-52s, are depainted in open facilities termed wash racks. E-3s are depainted in a paint/depaint hangar at OC-ALC; because of this aircraft's height, it cannot be stripped in the existing wash rack.

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1 Communications with Stacy Disco and Kevin O'Connor, Aircraft Production Engineering, Tinker AFB, Oklahoma, July–September 1996, Tel.: (405) 736-5986.

2 Communications with Kurt Aktansel, Environmental Compliance, Tinker AFB, Oklahoma, September 1996, Tel.: (405) 734-3002.

3 Communications with George Baxter, Aircraft Production Engineering, Tinker AFB, Oklahoma, October 1996–February 1997, Tel.: (405) 736-5986.

4 Communications with Jeannie Warnock, Environmental Management, McClellan AFB, California, August–September 1996, Tel.: (916) 643-2892.

(1) **OC-ALC.** Aircraft frame depainting occurs in two buildings at OC-ALC — Buildings 2122 and 2280. Building 2122 contains two wash racks; Building 2280 is a paint hangar. Building 2122 has 6500 yd^2 of floor space (100 yd x 65 yd). The wash racks in the building are located at opposite ends of the building; the middle of the building consists of a parts-stripping area. Each wash rack has a deep trough surrounding the stripping area to collect all of the spent stripper. In addition to the stripping solvent, 7000 to 10,000 gallons of water per KC-135, and 15,000 to 20,000 gallons per B-52, are required during the stripping process. Stripped solids are collected at the bottom of each trough; liquids are drained into a sewer that flows to the industrial wastewater treatment plant (IWTP). The sludge and solids at the bottom of the trough are periodically transferred to 55-gallon drums for disposal as hazardous waste by a contracted waste-disposal vendor. Air exhaust from the wash racks is provided by four 110,000-cfm fans over each rack.

Data describing depainting operations were obtained from the facility engineers and environmental managers.[1,2,3] It takes approximately 336 labor-hours to strip one KC-135 aircraft coated with epoxy paint. A crew of seven per shift (three shifts per day) can complete this stripping process in two days. A B-52 requires approximately 480 labor-hours to strip. A crew of 10 per shift can complete this process in two days. Each aircraft typically requires 12 to 15 55-gallon drums of the MC-based stripper.

For aircraft coated with a tough primer coating, such as Koroflex™, up to 28 55-gallon drums of MC-based stripper may be required. The required labor-hours also typically triple because as many as five applications of the MC-based stripper can be needed. Approximately one-third of the aircraft depainted at OC-ALC are coated with Koroflex™.

Following the application of the MC stripper, a "dwell" time (*i.e.*, the amount of time the stripper is left on the aircraft to penetrate the coating) of 15 to 60 minutes is allowed, depending on the toughness of the coating. Following the dwell time, the MC layer is scrubbed with hard-bristle brushes, a task that can take up to four hours depending on the type of primer/paint coating on the aircraft. After the aircraft is scrubbed, the stripper and paint are removed from its surface with a squeegee.

For all of these operations, crew members wear personal protective equipment (PPE), including a hard-cap with breathing air supply, a full wet-suit, Neoprene™ gloves, protective sleeves, and boots. Each person works up to two hours per rotation clothed in the PPE, to a maximum of seven hours a day of exposure. The breathing air is supplied by a generator. This air passes through a purifying system equipped with an alarm that also serves

as a monitor for the air quality. The ambient air is not monitored; however, when work has to take place in confined spaces, a lower explosive limit (LEL) check is made every four hours.

Between 45 and 55 KC-135 aircraft and between eight and 12 E-3 aircraft are stripped at OC-ALC per year. No recent data were available on the number of B-52s stripped.

(2) **SM-ALC.** The MC-depainting operation at McClellan AFB is managed by the weapon systems manager at OC-ALC. It is quite similar to the operation at OC-ALC, described above, and MC-stripper usage is approximately the same. About 20 KC-135 aircraft are depainted at SM-ALC per year in a wash rack housed in an open-door hangar (87 yd x 57 yd). Currently there is no forced-air exhaust system in this facility. The stripping process takes between 432 and 576 labor-hours. Both SM-ALC and OC-ALC require five to seven three-shift working days to complete the coating-removal process and prepare the aircraft for painting.

Responses to questionnaires and other data collected regarding MC-based stripping at these two ALCs are included in Appendix A.

b. <u>Advantages of Using MC</u>

Interviews with ALC personnel and operators of a commercial[5] depainting facility indicate that MC stripping is clearly the method of choice for rapid and efficient aircraft depainting. There is a high level of comfort with MC stripping because of the extensive long-term experience with the process and the existence of an infrastructure to support the use of this depainting method. While the data base concerning damage to metal aircraft frames from MC stripper use is small, experience and history confirm the absence of significant problems.

c. <u>Disadvantages of Using MC</u>

The impending aerospace rework NESHAP (2), and stricter AFOSH/OSHA standards, are the primary forces driving the AF toward eliminating the use of MC-based strippers. MC accounts for about 40 percent of the total toxic emissions to the atmosphere by the aerospace industry. Thus, for an existing operation to continue using MC for aircraft frame depainting, it must install control technologies capable of reducing MC emissions by 95 percent or more before the 1 September 1998 deadline. Moreover, in addition to posing a risk (however

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[5] Communications with Terry Johnson and William Stevens, Delta Airlines, Atlanta, Georgia, August 1996, Tel.: (404) 714-1159.

exaggerated) to health, MC use is also disadvantaged in that current practices generate large volumes of hazardous waste (spent stripping solvent) that require disposal at high cost.

2. Stripping with Alternative Chemicals

Alternative chemicals that have been used to remove paint coatings include *N*-methyl-2-pyrrolidone (NMP), dibasic esters (DBE), benzyl and furfuryl alcohols, alkyl acetates, and methyl ethyl and methyl amyl ketones. These alternative chemical strippers are used in the same manner as MC-based formulations, but typically require much longer soaks to soften and dissolve paint. These alternative chemicals are not currently classified as HAPs.

Products based on benzyl alcohol (BA) are the alternative chemical strippers of choice at the ALCs that use alternative chemical technologies. BA is currently being used at OO-ALC and WR-ALC to soften the paint on C-130 and C-141 aircraft frames before actual MPW/BOSS.

OC-ALC is presently evaluating a new BA-based product for use as an MC replacement in some of its operations. The product being tested consists of two separate components, marketed by El Dorado Chemicals[6] under the trade names PR-3140™ and PR-5000™. These two components are mixed just before application. While the exact composition of the stripper is proprietary, BA, hydrogen peroxide, and ammonia are its principal constituents. Full-scale depainting tests to evaluate the El Dorado BA-based stripper were conducted[3] on three aircraft between November 1996 and February 1997. The first test was performed during November 1996 on a KC-135 that had a Koroflex™ primer coating. The aircraft was depainted to specifications using eight 55-gallon drums of the product mixture. The task was completed in two-and-a-half applications requiring seven shifts. In comparison, the same task requires from 24 to 28 drums of MC-based stripper, up to five applications, and nine shifts.

The second test was performed in December 1996 with an epoxy-coated E-3. About 15 55-gallon drums of the BA product mixture were used. In this test, there was no significant difference in either the volume of the stripper used or the time required to depaint the aircraft, when compared to MC stripping.

The third test was performed on an E-3 aircraft whose fuselage was coated with Koroflex™ and whose wings were coated with epoxy. About 20 55-gallon drums of the BA product were required for successful depainting. For this test, there was a small decrease in the

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[6] Material Safety Data Sheet for Two Component Benzyl Alcohol Stripper, El Dorado Chemicals Products PR-3140 and PR-5000, provided by George Baxter, Aircraft Production Engineering, Tinker AFB, Oklahoma, October 1996–February 1997, Tel.: (405) 736-5986.

volume of stripper required but no significant savings in the time required for stripping. During use of the BA product, PPE was maintained at the level employed for MC-based stripping.

Delta Airlines has replaced its MC-based stripping operation with a process based on BA.[5] Delta selected a solution of BA containing formic acid (commercially available as Turco 6776™) as its MC replacement. This product differs in composition and pH from the one tested at OC-ALC. The Delta staff confirmed that the switch to the BA product has slowed the depainting production rate. Nevertheless, Delta has chosen to continue with alternative chemical stripping instead of MC-based stripping or any of the mechanical/abrasive methods. Of the mechanical methods, plastic-media blasting (PMB) is considered an unacceptable alternative for most of Delta's and its customers' aircraft. Other depainting methods (high-pressure water, FLASHJET™, CO_2 pellet blasting, etc.) are considered too expensive and/or currently technologically immature by Delta engineers.[5]

NMP is another alternative chemical stripper that is considered a candidate for MC replacement (1). Although no military or major commercial aircraft-frame-depainting operations are using NMP, NADEP Cherry Point is using NMP in two dip tanks to strip aircraft parts.[7] The dip time, which corresponds to dwell time, is a few hours, and varies somewhat with coating type. The Cherry Point operation reports satisfactory results from NMP; however, maintaining a bath temperature of between 160° and 180°F and keeping the NMP free of water are critical to the operation. Water in the NMP causes it to lose its effectiveness as a stripping agent, and preventing water contamination has proven to be a challenge to the Cherry Point operation.

a. Advantages of Using Alternative Chemicals

The most significant advantage to using alternative chemical strippers is that current alternative formulations contain no designated HAPs, and (as long as the non-HAP status persists) are exempt under the aerospace rework NESHAP from emission control requirements. The use of alternative chemicals (possibly excepting NMP) will require little or no transformation of an MC-based facility because stripping procedures are not changed. The cost of the most-popular alternative stripper, BA, is $1,100 per 55-gallon drum compared to $250 per drum for the MC-based strippers, but the greater cost of the BA product can be offset by reduced labor and reduced stripper usage in instances where these reductions are possible. Still, and most

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[7] Communications with Marc Mena, Cherry Point Naval Aviation Depot, Cherry Point, North Carolina, August 1996, Tel.: (919) 466-7166.

important, the BA products are not subject to the same regulations as MC, which avoids the need for costly containment and control equipment.

b. Disadvantages of Using Alternative Chemicals

Although emissions of currently available alternative chemical strippers are not regulated (as MC emissions are), this exemption is not guaranteed to persist. For example, Oklahoma City is currently in attainment for ozone. However, if the ozone ambient air quality standard is reduced to 0.08 ppm, 8-hour average, as proposed by EPA,[8] instead of the current 0.12 ppm, hourly average, Oklahoma City will become a non-attainment area. Lowering ambient ozone requires decreasing VOC emissions in the region. Thus, if Oklahoma City falls into non-attainment, the local air district will need to regulate VOC sources not regulated at present. These regulations would most likely include requiring Reasonably Available Control Technology (RACT) for aerospace coatings removal and paint spray booth operations. Thus, any such regulatory changes would affect depainting operations at OC-ALC.

Another disadvantage to the use of alternative chemical strippers is their potential to increase the rate of airframe corrosion. Aircraft skin corrosion data for the alternative chemicals are limited at present, so this may or may not prove to be a concern and disadvantage. Another potential disadvantage of alternative chemical strippers use relates to their unknown effects on base IWTP operation. IWTPs that are currently designed to treat wastewater contaminated with MC strippers may have to be reengineered to treat wastewaters contaminated by alternative chemical strippers.

3. Plastic-Media Blasting (PMB)

PMB is by far the most-widely used method of depainting within the military, accounting for about 32 percent of the total aircraft-frame surface area depainted in 1995 by the AF (see Table 2). Typically, smaller aircraft, such as F-15s, F-16s, and A-10s, are depainted using PMB in closed booths. The only large-aircraft PMB-depainting facility is at SA-ALC, where C-5s are depainted.[9] PMB is effective, eliminates the problems of HAP and VOC emissions, and creates only a fairly large volume of hazardous waste and controllable dust. However, operations using MC to depaint aircraft such as KC-135s, B-52s, B-1s, and E-3s (all Boeing aircraft) cannot be converted to PMB because Boeing has warned against the use of PMB more than once in the

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[8] Communications with Tom Diggs, Chief, Air Planning Section, EPA Region VI, Dallas, Texas, February 1997, Tel.: (212) 665-7214.

[9] Communications with Mike Haas, Kelly AFB, Texas, July–August 1996, Tel.: (210) 925-8541.

lifetime of aircraft it has manufactured. Accordingly, neither the AF nor any commercial facilities use PMB to depaint Boeing aircraft, and it is not an alternative to MC-based stripping for these existing applications.

4. Medium-Pressure Water/Bicarbonate of Soda Stripping (MPW/BOSS)

Blasting with medium-pressure water containing bicarbonate of soda (BOS) for abrasion has been shown by at least two manufacturers to effectively strip aircraft (5). The mild abrasion caused by the BOS allows the energy of the medium-pressure water blast to strip coatings from the substrate without the need to operate at higher water pressures. Typical operating conditions for an MPW/BOSS system are water pressure of up to 15,000 psi, water flowrate of about 3.2 gpm, and BOS addition rate of 0.33 lb/min (5). Two ALCs use the MPW/BOSS Aqua Miser™ process, OO-ALC to strip C-130 aircraft, and WR-ALC to strip both C-130 and C-141 aircraft.

a. WR-ALC

Information on the MPW/BOSS process at WR-ALC was obtained with the help of onsite contractor personnel.[10] Between January and October 1996, WR-ALC staff depainted 18 C-141 aircraft using a method that comprises three process steps: a preliminary application of BA over the entire aircraft, a subsequent dwell time of at least four hours, and removal of the BA and paint by gentle scraping with a squeegee or blasting with MPW/BOSS. After the third step, the aircraft is rinsed with warm water, allowed to dry, and examined to determine the adequacy of stripping or the need to repeat the process.

An average of 200 labor-hours is sufficient to depaint a C-141 without presoftening with BA; depainting a C-141 by MPW/BOSS requires 600 labor-hours. The task typically involves six to eight workers per shift and consumes an average of 165 gallons of BA and 5,000 lb of BOS. Depainting a C-130 consumes 110 gallons of BA and 10,000 lb of BOS. Water consumption is 40,000 to 50,000 gallons per aircraft. The cost of the BA stripper is $1,100 per 55-gallon drum, and the cost of BOS is $16 to $18 per 50-lb bag. Required PPE includes noise protection, safety goggles, supplied air, rain gear, and rubber boots. PPE use time is between 1 and 1.5 hours, on average. All waste generated is classified as hazardous waste. The liquid waste is sent to the IWTP for treatment, while the solid waste (sludge, paint chips, and BOS residue) is collected in drums and transported to a contracted waste disposal facility. Airflow and

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[10] Communications with Don Black, onsite Battelle contractor at Warner-Robins AFB, Georgia, October 1996, Tel.: (912) 328-6630.

sampling measurements in the depainting facilities are performed annually by Robins AFB's bioenvironmental engineering group.

Although the experience with MPW/BOSS at WR-ALC has been generally positive, some concerns exist about the potential corrosive and intrusive effects of BOS. Accordingly, scheduled modifications at WR-ALC include replacement of the BOSS step with a water-only blast using a new nozzle, which will allay these concerns.

b. OO-ALC

Environmental and engineering staff at OO-ALC[11] report that OO-ALC depaints only C-130 aircraft by the BA-enhanced MPW/BOSS process. The general procedures used at OO-ALC are similar to those used at WR-ALC. At OO-ALC, two separate coatings of BA are applied and allowed to dwell for 8 to 10 hours. The first application of BA is removed by squeegeeing the aircraft's surface. The second application is removed using the MPW/BOSS Aqua Miser™ process. About 440 gallons of BA, 2,500 lb of BOS, and 40,000 to 50,000 gallons of water are used per aircraft. OO-ALC staff are also concerned over the potential corrosive and intrusive effects of BOS, so they designed their process to use far less soda and more BA than WR-ALC's. At OO-ALC, the aircraft are treated above a trough that collects the depaint residue/ sludge and water. The sludge is transferred to 55-gallon drums for disposal; the liquid waste is pumped to the IWTP for treatment. Required PPE includes a mask with supplied breathing air, plus rain gear and rubber boots. A total of 256 labor-hours are required at OO-ALC to depaint a C-130. Eight personnel per shift perform the depainting, four persons at a time wearing PPE and rotating out of the process after four hours.

c. Advantages of Using MPW/BOSS

The MPW/BOSS system has no HAP emissions. The Aqua Miser™ equipment, which costs between $40,000 and $70,000, can almost seamlessly be installed to replace an MC-based operation. The full conversion cost of an MC-based operation for C-130 aircraft was estimated[1] in 1994 to be about $645,000.

d. Disadvantages of Using MPW/BOSS

Water and bicarbonate of soda can intrude into seams and cracks in the stripped substrate. This potential problem is made worse by the possibility that sealant materials are also

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[11] Communications with John Vidic and Glenn Baker, Hill AFB, Utah, July–October 1996, Tel. (Vidic): (801) 777-2050; Tel. (Baker): (801) 777-9076.

removed along with the paint during blasting with medium-pressure water. Delta Airlines personnel stated that, because of these two potential problems, the MPW/BOSS process was eliminated as an MC replacement candidate for Delta[5].

C. EMERGING DEPAINTING TECHNOLOGIES

1. Large-Area Robotic Paint Stripping System with High-Pressure Water Blasting (LARPS/HPW)

Under a program sponsored by the Manufacturing Technology Directorate, United Technologies Corporation developed an automated paint stripping system that uses high-pressure water in a manner not expected to damage thin-skinned aircraft surfaces. The program to develop this LARPS process was initiated in 1991 with an objective of establishing an automated, low-cost, environmentally safe paint-removal system for aircraft frames and components at OC-ALC. The LARPS program was subsequently extended as a joint venture between Wright Laboratories, the U.S. Navy, OC-ALC, and Water-Jet Systems, a prime contractor.[12] The LARPS system, currently undergoing validation testing at OC-ALC, uses high-pressure water to strip paint. The system consists of a nine-axis oval robot that moves on an automatically guided vehicle platform and blasts water at about 20 gpm at a pressure of 28,000 psi. By using rotary nozzles and properly adjusting process parameters, the system can be adjusted to remove single layers of paint from thin-walled metal surfaces (*e.g.*, soft-clad aluminum). The capital costs for installing such a system are expected to be in the range of $4.0M. If successful, the process is expected[12] to replace 50 percent of the MC-depainting capacity for KC-135 aircraft by mid-1997.

a. Advantages of Using LARPS/HPW

The expected stripping rate of the process is excellent, at between 100 and 175 ft^2/hr. The LARPS/HPW system emits no HAPs. Because it will be a fully automated process, depainting personnel requirements will be decreased by 50 percent or more[12] (it is expected that only two persons per shift will be required to operate the system). PPE will not be necessary, resulting in significant further cost savings. In addition, the blasting water can be recycled indefinitely after filtration, eliminating the cost of liquid waste treatment.

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[12] Communications with Randel Bowman, LARPS engineer, Tinker AFB, Oklahoma, August 1996, Tel.: (405) 736-4178. Also:
(1) http://www.wl.wpafb.af.mil/mtx/htm/afst/app.htm
(2) http://clean.rti.org/la_gen.htm
(3) http://es.inel.gov/new/funding/serdp/p2prj020.html.

b. Disadvantages of Using LARPS/HPW

Improper application of the LARPS/HPW system can seriously damage the substrate. The water-jets are capable of cutting through an aluminum-clad skin. Furthermore, like MPW/BOSS, water can intrude into the seams and cracks in the stripped substrate, and sealant materials could be removed along with the paint. Delta Airlines personnel acknowledged that Lufthansa, which pioneered the use of a similar HPW system for depainting in 1992, has discontinued its use for these very reasons. Delta personnel further consider even the current LARPS/HPW technology to be too immature for use in its facility at this time.[5]

2. Wheat-Starch Blasting[9] (6)

Wheat starch is a blasting medium that is less abrasive than PMB. This blasting medium is a crystallized form of wheat starch that is non-toxic, biodegradable, and made from renewable resources. It can be used with any blasting unit designed for PMB use. Boeing has approved the use of the wheat-starch medium for both metal and composite aircraft surfaces, including thin-clad aluminum at fuselage structures. For most current applications, the medium is delivered at less than 35 psi nozzle pressure. This prevents damage to the substrate under the coating. The technology is still at the demonstration stage, however, and must be further tested at full-scale before being considered a practical alternative for MC-based processes.

3. FLASHJET™ Coating Removal System[13]

The FLASHJET™ process, developed by McDonnell–Douglas, uses a simultaneous pulse of light energy and a low-pressure CO_2 (Dry Ice™) particle system that sweeps away the coating residue after impact. An evacuation-and-capture subsystem collects the total removed coating particles. The entire system is fully automated, although it has not yet been demonstrated on large aircraft. A prototype system is currently being tested for military use at the National Defense Center for Environmental Excellence (NDCEE).[14] If its performance is acceptable, it will enjoy such significant advantages as no organic HAP emissions, low residual waste volumes, ease of control, varying degrees of coating removal, and substantial reduction in personnel and

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[13] FLASHJET, vendor brochure, McDonnell–Douglas Aerospace, MC 106-4297, St. Louis, Missouri, undated.

[14] Communications with Frederick A. Lancaster, NDCEE and Concurrent Technologies Corporation, Johnstown, Pennsylvania, August 1996, Tel.: (814) 269-6462. http://www.ndcee.ctc.com.

PPE requirements per aircraft stripped. The capital cost for a FLASHJET™ system is estimated to be between $2.0M and $2.5M.

4. Laser Stripping

A stationary, 6-kW laser-based, paint-stripping system is currently[11] in use at OO-ALC for removing paint from aircraft radomes. A similar, though smaller, system is installed at the Corpus Christi Army Depot for stripping coatings from helicopter rotor blades constructed from composites. The advantages of using laser-based paint stripping include low residual waste volumes, decreased aircraft preparation and post-stripping cleanup requirements, and decreased requirements for PPE and personnel monitoring. Laser-based systems have been successfully used by the military to depaint small parts, as noted above (7), and both the Navy and the AF have investigated laser-based paint stripping for use on large-aircraft frames (7). To achieve cost-effective paint stripping in these applications, the laser energy source requires real-time computer-controlled management and control of the laser beam, the surface-monitoring subsystem, the positioning subsystem, and the waste-collecting subsystem. Although production prototypes of these subsystems exist, they have not been fully integrated and tested as yet. Thus, further development and evaluation – particularly of the management-and-control software – are needed before laser-based paint stripping of large aircraft can be realized.

5. Barrier Coatings (8)

Although the use of barrier coatings is not a paint-stripping method, it can have significant effects on the use of abrasive paint-stripping methods and, thus, deserves comment. PMB, MPW/BOSS, and other abrasive paint-removal methods may be environmentally friendly, but they can damage aircraft surfaces. A current program sponsored by McClellan AFB seeks to develop and scaleup the manufacture of a zero-VOC, transparent, PMB-resistant barrier coating to be placed between composite skins and conventional primers and paints. Preliminary tests indicate that this unique epoxy–silane resin, known as HRG-3, can prevent damage to composites during simulated PMB depainting. The use of such barrier coatings may broaden the range of aircraft types on which PMB and other abrasive technologies can be used, especially those aircraft that currently use MC-based strippers and cannot tolerate PMB.

Table 3 presents a qualitative comparison of the various depainting technologies described above.

TABLE 3. OVERALL COMPARISON OF TECHNOLOGIES TO DEPAINT AIRCRAFT SURFACES.

Depainting Technology	MC-Based Stripping	Alternative Chemical Stripping	PMB	MPW/BOSS After Presoftening with BA	LARPS/HPW	Laser Stripping	Wheat Starch Blasting	FLASHJET™ with CO_2 Pellet Blasting
Stripping rate	Medium	Medium	Med–High	Low–Med	Med–High	High	Low–Med	High
Level of required PPE	High	High	Med–High; Low for automated	High	Low	Low	Low	Low
Labor-hour requirement	High	High	High; Low for automated	High	Low	Low	High	Low
Compatibility	Medium	Medium	Med–High	Medium	High	High	High	High
Corrosion potential	Low	Low–Med	Low	Med–High	High	Low	High	Low
Intrusion potential	High	High	Medium	High	High	Low	High	Low
Pre-stripping preparation requirements	High	High	High	High	High	Low	High	Low
Post-stripping cleanup requirements	High	High	Medium	High	Low	Low	Medium	Low
Residue volume	High	High	High	High	High	Low	High	Low
Residue demands on IWTP requirement	High	High	High	High	High	Low	High	Low
Air pollution control requirement	High	Low–Med	Medium	Medium	Low	Low	Low	Low
Current status of technology in the AF	Wide use since ca. 1940s	Components only; under testing for frames	Wide use since ca. 1989	Aircraft frames only since ca. 1994	Aircraft frames at OC-ALC since ca. mid-1997	Radomes at OO-ALC; under investigation for frames	Demo-stage; under testing	Under testing at NDCEE for military use
Initial capital costs for conversion from MC-based stripping	None	Low	Medium	Low	High	High	Medium	High

D. REGULATORY AND HEALTH AND SAFETY ISSUES

1. Aerospace Rework NESHAP

As discussed earlier, for the use of MC-based strippers to continue, containment-and-control technologies capable of decreasing HAP emissions by at least 95 percent must be in place by September 1998. A summary of some of the requirements of the aerospace rework NESHAP applicable to aircraft-frame depainting is given in Table 4.

OC-ALC and SM-ALC combined used about 66,000 gallons (660,000 lb) of MC-based paint-stripper formulation to depaint aircraft surfaces in 1995. The environmental compliance officer at Tinker AFB noted that the 1995 base emission inventory report to the state of Oklahoma estimated emissions of 176 tons (352,000 lb) of MC and 50 tons (100,000 lb) of phenol from all MC-based activities within Building 2122[2] (the primary MC depainting facility at Tinker AFB), and 23 tons (46,000 lb) of MC and 9 tons (18,000 lb) of phenol from Building 2280 (the depainting facility for E-3s). For compliance and inventory purposes, Tinker AFB engineers calculate air emissions as 83 percent of the total MC and phenol usage. Table 5 summarizes MC-based stripper usage for aircraft frame depainting at Tinker AFB during 1995, and notes the reductions needed to be achieved to comply with the aerospace rework NESHAP. The aerospace rework NESHAP assumes that all the HAPs used for depainting are emitted in the absence of containment/control.

2. Local Regulations

Tinker AFB is subject to Oklahoma state regulations. Under Oklahoma rules, MC is a Class A compound (highly toxic) with *de minimis* emission values of 0.57 lb/hr or 1,200 lb/year. Exceedences outside the property line are subject to modeling.[15]

McClellan AFB has a permit for its depainting operations, with limits set specifically for these operations on the basis of health risk assessment modeling performed by a contractor.[16]

3. Health and Safety

The health and safety standards throughout the AF are set by the AF Office of Safety and Health (AFOSH). AFOSH, at a minimum, adopts OSHA standards, although in many cases AFOSH imposes stricter standards. Until recently, AFOSH set the maximum allowable workplace

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[15] Communications with Hal Wright, Oklahoma Air Pollution Control Department, Oklahoma City, Oklahoma, October 1996, Tel.: (405) 290-8247.

[16] Communications with Bruce Nixon, Sacramento Metropolitan Air Quality Management District, Sacramento, California, October 1996, Tel.: (916) 386-6623.

TABLE 4. SUMMARY OF AEROSPACE REWORK NESHAP — AIRCRAFT FRAME DEPAINTING (2).

- Aerospace Rework NESHAP:
  - — Proposed 6 June 1994 (59 FR 29216)
  - — Finalized 1 September 1995 (60 FR 45048)

  Contains MACT standards for cleaning/coatings removal; requires emission control on processes that release HAPs
- NESHAP compliance dates:
  - — Existing sources: 1 September 1998
  - — New sources (started construction 6 June 1994 and later): 1 September 1995
- Features of the MACT standards for depainting operations
  - — Organic and inorganic HAPs are controlled; the standard primarily addresses outer-surface depainting, *e.g.*, fuselage, wings, and stabilizers
  - — Emissions of all organic HAPs in strippers must be decreased by use of a control system
  - — Control systems in use before 1 September 1995 must achieve 81% organic HAP emissions reductions, or greater
  - — Control systems in use after 1 September 1995 must achieve 95% organic HAP emissions reductions, or greater
  - — Reductions must take into account capture, destruction and removal efficiency, and volume of chemical used
  - — Baseline emissions must be calculated using data from 1996/1997, and should be based on a usage per aircraft, or usage per ft^2 of surface depainted

TABLE 5. MC USAGE FOR AIRCRAFT FRAME DEPAINTING AT OC-ALC DURING 1995.

Parameter	Bldg. 2122	Bldg. 2280	Total
Aircraft type	KC-135	E-3	—
Number of aircraft depainted	50	10	60
Stripper usage, lb	410,000	82,000	492,000
Methylene chloride usage, lb (50% by wt. of stripper formulation)	205,000	41,000	246,000
Phenol usage, lb (20% by wt. of stripper formulation)	82,000	16,400	98,400
Allowable emissions after September 1998:			
Methylene chloride, lb (after 95% reduction)	<10,250	<2,050	<12,300
Phenol, lb (after 95% reduction)	<4,100	<820	<4,920

air MC concentration in depainting facilities at the threshold limit value (TLV) established by the American Conference of Governmental Industrial Hygienists (ACGIH). This limit is 50 ppm, 8-hour time-weighted average (TWA). Until January 1997, this allowable concentration was more stringent than the OSHA standard of 500 ppm, 8-hour TWA. However, in January 1997, OSHA lowered (9) its permissible exposure limits (PELs) for MC. The 8-hour TWA was reduced to 25 ppm; and the former short-term exposure limit (STEL) of 2,000 ppm (measured over 5 minutes in any 2-hour period) was reduced to 125 ppm, 15-minute TWA. In addition, OSHA set an "action level" of 12.5 ppm, 8-hour TWA. (At this action level of half the PEL, a warning is issued for action to be taken to ensure that the level does not go over the PEL. When worker exposure exceeds the permissible limits, use of PPE becomes mandatory.) Upon promulgation of the revised OSHA standards for MC exposure, AFOSH promptly adopted the same standards.

In a recently published study, occupational exposures to MC were assessed during paint stripping of aircraft frames and components at a NADEP (10). The assessment was performed using 47 TWA measurements and three statistical techniques. Exposures were measured for four stripping activities: component stripping, aircraft-frame stripping, stripping of aircraft intakes, and stripping in enclosed areas. The stripping was performed on A-6, F-14, and, occasionally, F-15 or F-16 aircraft, and their respective components. The three statistical methods used to analyze the data were the Rappaport method, the modified Cox method, and the one-sided tolerance limit (OTL) method. The results of the analysis are presented in Table 6. (No statistical analyses were performed with the enclosed-area data as too few measurements were taken.)

All three statistical evaluations indicated that MC exposure during the stripping of aircraft intakes was unacceptable, whereas exposure during the stripping of components was acceptable. For aircraft-frame stripping, exposures met the OSHA PEL for two of the statistical tests, but failed for the third test. The test giving the unacceptable results, the OTL method, is the most-conservative method of the three, and is suggested for use when compliance issues are being assessed.

Air sampling at the MC-depainting facilities at OC-ALC is performed once a year to assess compliance with the AFOSH/OSHA workplace standards. The sampling is performed by the base bioenvironmental engineering group. The bioenvironmental engineer at Tinker AFB reported[2] that past sampling data for the air in Building 2122 showed its TWA MC concentration during depainting operations to be about 75 ppm. Workplace air sampling is not routinely performed at the SM-ALC MC depainting facility.

TABLE 6. RESULTS OF STATISTICAL ANALYSES OF OCCUPATIONAL EXPOSURE TO MC AT A NADEP AIRCRAFT STRIPPING FACILITY.[14]

Standard	Statistical Test	Activity		
		Component Stripping	Aircraft Frame Stripping	Intake Stripping
OSHA	OTL	A[a]	U[b]	U
8-hr TWA	Rappaport	A	A	U
25 ppm	Cox	A	A	U

[a]A = Acceptable.
[b]U = Unacceptable.

As noted in Section I, one of the goals of this project is to evaluate the potential for controlling MC emissions at AF facilities (see Section II.B.1). The cost of an MC-control system in most cases is generally in direct proportion to the facility exhaust air flowrate. Therefore, one way to reduce the cost of an MC control system is to reduce the flowrate of the exhaust air controlled. As discussed in Section IV, the maximum controlled air stream flowrate for which MC control costs are not unrealistic is in the 50,000 to 60,000 cfm range. The exhaust air flowrate from Building 2122 at Tinker AFB is about 425,000 cfm. Reducing the flowrate to 60,000 cfm will increase the building air MC TWA concentration from the 75-ppm level noted above to more than 500 ppm. This increase in workplace MC concentration will dictate an increase in the required level of PPE. At present, workers at Tinker AFB wear a loose-hood supplied-air respirator that provides a protection factor of 25. At an increased workplace MC concentration of more than 500 ppm, however, a protection factor of at least 150 will be required to maintain acceptable worker exposure levels. The requirement to work in this more-protective PPE will most likely lead to more-frequent worker rotation and overall reduced efficiency; it will slightly increase the risk of health consequences resulting from an event which is consistent with the intent of and guidance in DoDD 5000.1 and DoDI 5000.2.

E. REFERENCES FOR SECTION II

1. Thomas, R., Rogan, S., Paulson, S., Craig, P., Rogers, M., White, R., Ottmar, L., and Malley, P., Aerospace NESHAP Guidance: Painting and Depainting Alternatives for Selected DoD Operations, Lockheed–Martin Environmental draft report under U.S. EPA Contract 68-C4-0020, 1996.

2. National Emission Standards for Aerospace Manufacturing and Rework Facilities, 40 CFR 63, Subpart GG.

3. Emission Inventory Report for the Warner–Robins Air Logistic Center, Acurex Environmental draft report under U.S. EPA Contract No. 68-D2-0063, 1993.

4. TO 1-1-8, USAF Technical Manual for the Application and Removal of Organic Coatings, Aerospace and Non-Aerospace Equipment, September 1989, Change 7, March 1992.

5. Joint EPA/NASA Interagency Depainting Study, First Quarterly Report, August 1994.

6. Paint Stripping using Wheat Starch Blasting, Tri Services' P2 Technical Library, maintained by the Naval Facilities Engineering Service Center (NFESC) Revised August 1996. http://clean.rti.org/larry/depaint8.htm.

7. Wool, M., "Environmentally Friendly Paint Stripping of Aerospace Composites Using a Computer-Controlled Laser," Proceedings of the First Annual Joint Service Pollution Prevention Conference and Exhibition, San Antonio, Texas, p. 363, August 1996.

8. Burnett, C. R., Tuniclk, S. A., and Siebold, R. W., "HRG-3: A New Zero-VOC Sprayable Epoxy–Silane Barrier Layer Coating for Protecting Composite and Aluminum Aircraft Skins during Depainting Operations," Proceedings of the First Annual Joint Service Pollution Prevention Conference and Exhibition, San Antonio, Texas, p. 358, August 1996.

9. 29 CFR Parts 1910, 1915 and 1926, Occupational Exposure to Methylene Chloride. http://www.access.gpo.gov.

10. Kimbrough, J. D., Crowder, L. D., and McElhiney, J., "Three Statistical Techniques Used to Assess Methylene Chloride Exposures during Aircraft Paint Stripping at a Naval Aviation Depot," Poster Presentation at the 1996 AIChE Conference, May 1996, Chicago, Illinois. Also, communication with J.D. Kimbrough, Naval Medical Center Portsmouth, Norfolk, Virginia, Tel.: (757) 444-7610.

SECTION III

ESTIMATION OF OPERATING COSTS FOR EXISTING AIR FORCE DEPAINTING FACILITIES AND POTENTIAL ALTERNATIVE TECHNOLOGIES

A. INTRODUCTION

One of this document's goals is to provide guidance for performing evaluations of the costs of alternative technologies to MC-based paint stripping. This section outlines a method for obtaining ROM cost estimates for operating MC-based aircraft depainting operations and for four alternative depainting processes. Of the various depainting methods discussed in Section II as potential MC replacements, four depainting technologies were selected for the cost analysis: MPW/BOSS with BA presoftening, the two-component BA chemical stripper, the LARPS system, and the laser stripping system. The AF has varying degrees of experience with MC-based stripping and the four alternative technologies. While the other technologies described in Section II may be potential alternatives to MC-based stripping, they are not considered here because of their potential lack of compatibility with aircraft skins, and their need to undergo further research and development.

MPW/BOSS after presoftening with BA has been in use in the AF for aircraft depainting at OO-ALC and WR-ALC for more than three years.[1] The two-component BA stripper is undergoing testing at OC-ALC as a potential alternative to MC-based aircraft stripping.[2] A LARPS system is also undergoing validation testing at OC-ALC, and is expected[3] to become fully operational for the depainting of KC-135 aircraft by mid-1997. Although there has been no experience within the AF in the use of laser-based stripping processes for aircraft frames, a laser-

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[1] Communications with Don Black, onsite Battelle contractor at WR-ALC, Robins AFB, Georgia, October 1996, Tel.: (912) 328-6630.

[2] Communications with George Baxter, Aircraft Production Engineering, Tinker AFB, Oklahoma, October 1996–February 1997, Tel.: (405) 736-5986; and with Stacy Disco and Kevin O'Connor, Aircraft Production Engineering, Tinker AFB, Oklahoma, July–September 1996, Tel.: (405) 736-5986.

[3] Communications with Randel Bowman, LARPS engineer, Tinker AFB, Oklahoma, August 1996, Tel.: (405) 736-4178. Also:
(1) http://www.wl.wpafb.af.mil/mtx/htm/afst/app.htm
(2) http://clean.rti.org/la_gen.htm
(3) http://es.inel.gov/new/funding/serdp/p2prj020.html

based system for depainting radomes is in place at OO-ALC. In addition, the Corpus Christi Army Depot has had some experience with laser stripping of helicopter rotor blades (1).

The example generated to illustrate this cost-estimating procedure is converting the existing MC-based depainting operation at OC-ALC to each of the alternative technologies in turn. However, the procedure outlined can be easily applied to other facilities and other processes. The information given in Table 7 illustrates one of the key challenges to developing cost estimates for MC stripping and the selected candidate replacement processes. As shown in the table, MC stripping is used by the AF to depaint only B-1s, B-52s, KC-135s, and E-3s, while MPW/BOSS is used to depaint only C-130s and C-141s. Thus, no aircraft type is depainted via both processes, a fact that frustrates the development of consistent cost comparisons. To overcome this limitation, stripping-process operating costs have been normalized to a basis of unit surface area stripped, *i.e.*, $\$/ft^2$ stripped. This normalization causes some process costs that are weak functions of total surface area stripped to be slightly misrepresented, and some costs that are aircraft- or location-specific to be distorted. However, keeping in mind that the costs are intended to be ROM estimates, the estimates and conclusions drawn from comparing them are defensible.

B. OPERATING-COST DATA AND DERIVED COST ESTIMATES FOR COST ELEMENTS

The major factors that contribute to the operating cost of an aircraft-paint-stripping process are as follows:

- Raw material
- Labor
- Utilities
- PPE

TABLE 7. EXISTING AF AIRCRAFT DEPAINTING FACILITIES USING MC AND MPW/BOSS.

Site	Aircraft Type	Primary Existing Depainting Method
OC-ALC	B-1	MC-based stripper
	B-52	MC-based stripper
	KC-135	MC-based stripper
	E-3	MC-based stripper
WR-ALC	C-130	MPW/BOSS with BA presoftening
	C-141	MPW/BOSS with BA presoftening
SM-ALC	KC-135	MC-based stripper
OO-ALC	C-130	MPW/BOSS with BA presoftening

- Disposal of hazardous waste
- Training and medical

The following subsections discuss cost input data, and develop cost estimates for each of the above components for the five depainting process considered. The estimated operating costs for MC-based stripping and for MPW/BOSS are based on data from existing operations. The two-component BA, LARPS, and laser stripping processes are emerging technologies, and the estimated operating costs for these are based on preliminary and projected data. Depainting-process-cost data, as mentioned in Section II, were obtained from a number of sources including AF base personnel, onsite contractors, and selected documents and reports. Table 8 summarizes AF experience data for the two depainting processes in current use.

1. Raw Materials

a. MC-Based Stripping

The average cost of the MC-based stripper used at OC-ALC and SM-ALC is $250 per 55-gallon drum ($4.5/gallon). The discussion in Section II.B.1 noted that, on average, 12 to 15 drums of MC stripper are required per polyurethane/epoxy-coated aircraft, and 24 to 28 drums are required per Koroflex™-coated aircraft for KC-135s or B-52s depainted at OC-ALC. About one-third of the annual MC-based depainting load at OC-ALC consists of Koroflex™-coated aircraft. At SM-ALC, nine to 15 drums of MC-based stripper are consumed per KC-135 aircraft. (The reason why SM-ALC apparently uses less MC stripper than OC-ALC for KC-135s is unclear.) Given these usage rates, the average cost of the MC stripper at OC-ALC (taking into account that

TABLE 8. CURRENT DEPAINTING EXPERIENCE.

Aircraft Type	Location	Depainting Process	Number of Aircraft Depainted Annually[a]	Average Aircraft Surface-Area ft^2
KC-135	OC-ALC[b]	MC	50	9,600
	SM-ALC	MC	20	9,600
B-52	OC-ALC	MC	18	14,000
C-130	WR-ALC	MPW/BOSS	18	12,836
	OO-ALC	MPW/BOSS	50	12,836
C-141	WR-ALC	MPW/BOSS	21	17,425

[a]Based on 1995 and 1996 information.
[b]Potential applications of LARPS and two-component BA by mid-1997.

33 percent of the aircraft load is Koroflex™-coated) is $4,400 per aircraft (KC-135 or B-52), and at SM-ALC is $3,000 per KC-135 aircraft. The percentage of Koroflex™-coated aircraft depainted at SM-ALC was unknown and assumed to be zero.

Masking agents and other items required to prepare an aircraft for depainting add to the cost of raw materials. It was assumed, based on communications with AFB depainting personnel, that the cost of other raw materials is about five percent of the stripper costs. Thus, the overall cost of raw materials is about $4,600 per aircraft at OC-ALC, and about $3,100 per aircraft at SM-ALC.

b. MPW/BOSS after Presoftening with BA

The cost of BOS is about $17 per 50-lb bag ($0.34/lb), and the cost of BA presoftener is $1,100 per 55-gallon drum ($20/gallon). On average, three drums of BA and 5,000 lb of BOS are consumed per C-141 aircraft at WR-ALC. For each C-130, two drums of BA and 10,000 lb of BOS are consumed at WR-ALC. At OO-ALC, about eight drums of BA and 2,500 lb of BOS are used for each C-130 aircraft. At these usage rates, the average cost of stripping agents for this process is $5,000 per C-141 aircraft at WR-ALC; $5,600 per C-130 aircraft at WR-ALC; and $9,650 per C-130 aircraft at OO-ALC. According to information from both the ALCs that use this process, the exact quantities of BA and BOS used vary from one aircraft to another, but the above quantities represent good average values. The cost of other raw materials is again assumed to be 5 percent of the stripper cost. Thus, the overall cost of raw materials for the MPW/BOSS process is about $5,300 per C-141 aircraft at WR-ALC; $5,900 per C-130 aircraft at WR-ALC; and $10,100 per C-130 aircraft at OO-ALC.

c. Two-Component BA Stripping

The average cost of the two-component BA stripper is $950 per 55-gallon drum ($17.30/gallon). Preliminary full-scale tests conducted at OC-ALC on KC-135 and E-3 aircraft have shown that, for epoxy-coated aircraft, the amount of stripper used was the same as that required for MC-based stripping (12 to 15 drums). However, only eight drums were needed for a Koroflex™-coated KC-135 aircraft. At these rates, the average usage of the BA stripper is 642 gallons per aircraft (assuming that it is the replacement for the MC operation at OC-ALC and the distribution within the aircraft load remains 33-percent Koroflex™-coated). Thus, the cost of stripper per KC-135 aircraft is $11,100. Once again assuming that other raw materials add 5 percent to the stripper cost, the overall cost of raw materials per aircraft is about $11,650.

d. **LARPS**

The LARPS system uses high-pressure water as the stripper, but filters and reuses the process water indefinitely. Costs for the small amount of makeup water are neglected. Requirements for other raw materials, such as masking agents, are expected to be reduced significantly compared to the chemical processes. Given this, the cost of masking agents and other raw materials is assumed to be $100 per KC-135 aircraft (approximately half the cost of other raw materials for the MC-based operation).

e. **Laser Stripping**

The laser system uses high-energy pulses to remove paint coatings. This system has the advantage that it virtually eliminates the concerns of media intrusion into surface cracks and seams associated with the other processes discussed above. Thus, no masking agents will be required and there are no raw material costs associated with laser stripping.

2. **Labor**

A 1992 study by Rankin and Mendelsohn (2) estimated that the labor rates (including overhead) for supervisors and for workers averaged $19 per hour for the MC-based aircraft depainting operation in Building 2122 at OC-ALC. This rate was estimated for an operation in which 51 (37 KC-135 and 14 B-52) aircraft were depainted annually. By assuming an annual average increase of 4 percent, we estimate the 1997 average labor rate to be $23 per hour. In other locations, the labor rate may be expected to vary somewhat as a function of the stripping process used, the facility location, and the composition of the workforce (supervisor-to-worker ratio). However, for the purposes of this report, labor costs are assumed to be constant at $23 per hour for all of the processes.

a. **MC-Based Stripping**

For KC-135 stripping at both OC-ALC and SM-ALC, seven persons per 8-hour shift are employed. At OC-ALC, stripping Koroflex™-coated aircraft (33 percent of the load) requires nine shifts, while stripping epoxy/polyurethane-coated aircraft requires about six shifts. At SM-ALC, stripping a KC-135 (all with epoxy/polyurethane coating) requires nine shifts. For each B-52, at OC-ALC, 10 workers per shift are employed, and paint stripping requires six shifts on average. Pre- and post-paint stripping activities are each assumed to take half the number of the labor hours required for stripping, based on information from OC-ALC and SM-ALC. Table 9 presents a summary of these labor requirements and costs.

TABLE 9. LABOR REQUIREMENTS AND COSTS FOR MC-BASED STRIPPING.

Aircraft	**KC-135**	**B-52**	**KC-135**
Location	**OC-ALC**	**OC-ALC**	**SM-ALC**
Labor hours			
Pre-stripping	196	240	196
Stripping	392	480	504
Post-stripping	196	240	196
Total	784	960	896
Total Cost (@$23/hr)	$18,000	$22,100	$20,600

b. MPW/BOSS after Presoftening with BA

Stripping a C-130 at WR-ALC and OO-ALC requires eight workers on each of four 8-hour shifts when the MPW/BOSS process is used, a total of 256 labor hours per C-130. Data from WR-ALC show that the C-141 requires the same number of labor hours, 256, as the C-130, even though the C-141 has a larger surface area (see Table 8). Pre- and post-depainting activities are again assumed to take half the number of the labor hours required for stripping, based on information from WR-ALC and OO-ALC.[1,4] Table 10 summarizes these labor requirements and costs.

c. Two-Component BA Stripping

The two-component BA process requires the same amount of time as the MC-based process for stripping epoxy/polyurethane coatings (see Section II.B.2). However, it can strip Koroflex™-coated aircraft in less time than the MC-based stripper. On average, the BA stripping process requires 336 labor hours for a KC-135 aircraft at OC-ALC, assuming that the workload comprises 33-percent Koroflex™-coated aircraft. Assuming an additional 336 hours for combined pre- and post-stripping activities, the total cost of labor is about $15,500 per aircraft.

[4] Communications with John Vidic and Glenn Baker, Hill AFB, Utah, July–October 1996, Tel. (Vidic): (801) 777-2050; Tel. (Baker): (801) 777-9076.

TABLE 10. LABOR REQUIREMENTS AND COSTS FOR MPW/BOSS.

Aircraft	**C-130 and C-141**
Location	**OO-ALC and WR-ALC**
Labor hours	
Pre-stripping	128
Stripping	256
Post-stripping	128
Total	512
Total Cost (@$23/hr)	$11,800

d. LARPS

The stripping rate of the LARPS process currently being installed at OC-ALC is expected to be about 2.5 ft^2/min, or 150 ft^2/hr. Thus, 64 hours (eight shifts) will be needed to strip a KC-135 aircraft, which has a surface area of about 9,600 ft^2. Assuming three personnel per shift[3], the labor requirement translates to 192 labor hours. Pre- and post-stripping labor requirements are expected to be far less than those required for the MC-based operation; they are assumed here to be, in total, half (196 labor hours) of those required for the MC-based stripping operation. The total labor cost for depainting a KC-135 using the LARPS process is thus about $8,900 per aircraft.

e. Laser Stripping

The stripping rate of the laser process is assumed to be 60 ft^2/hr (see Section II.C.4). Thus, 160 hours (20 shifts) are required to strip a KC-135 aircraft (9,600 ft^2 surface area). Again assuming three personnel per shift, the requirement translates to 480 labor hours. It is reasonable to assume that pre- and post-stripping activities will be negligible. Thus, the labor cost for laser-based depainting is about $11,000 per aircraft.

3. Utilities

The utility costs associated with depainting are those related to the use of exhaust fans; water pumps; air compressors; heating, ventilation, and air conditioning (HVAC); and lighting. The cost of electricity is assumed to be $0.07 per kWh.

a. MC-Based Stripping

The cost of utilities for depainting aircraft in the section of Building 2122 at OC-ALC in which KC-135 aircraft are depainted was estimated using the fan-power requirements to exhaust 440,000 cfm of building air. Building 2122 is the primary MC-based depainting facility in the AF, and almost 75 aircraft are depainted there each year. All other power requirements are assumed to be half of the fan-power requirements. At SM-ALC, depainting occurs in a washrack comparable in size to the one section of Building 2122 (see Section II.B.1). However, at present, there are no exhaust fans to ventilate the facility, so depainting is performed with the hangar open.

It is assumed that the fans in Building 2122 operate continuously during the entire stripping process, which requires 48 hours (six shifts). The electrical power needed to drive the fans for these 48 hours is estimated to be 500 kWh. All other equipment is assumed to require half this much power, or 250 kWh. The cost of utilities for aircraft paint stripping at Building 2122 is thus about $50 per aircraft. At SM-ALC there are no fan-power requirements, so the total cost of utilities for aircraft paint stripping is assumed to be about $20 per aircraft.

b. MPW/BOSS after Presoftening with BA

C-141 aircraft at WR-ALC are depainted in Building 54. The peak exhaust air flowrate varies from 450,000 cfm in the winter to 600,000 cfm in the summer. The fans are not operated continuously during the stripping process. C-130 aircraft at WR-ALC and OO-ALC are depainted in open-door facilities, and the air is exhausted naturally.

All three facilities need 32 hours (4 shifts) to depaint an aircraft. To depaint a C-141, electrical power requirements are estimated to be about 160 kWh for fan operation (based on an average of 525,000 cfm capacity), and 80 kWh (half the fan requirement) for all other equipment. Thus, the cost of utilities for the stripping process is about $17 per C-141 aircraft. For the C-130 aircraft, which are depainted in open hangars, there are no fan-power requirements. Nevertheless, power requirements are assumed to be $17 per C-130 aircraft — the same as for a C-141.

c. Two-Component BA Stripping

The process engineer in charge of the evaluation of the BA product at OC-ALC indicated that the stripping process is expected to operate in a manner similar, in most respects, to the current MC-based process for depainting a KC-135. This includes the current facility configuration and exhaust air flowrates. Thus, the total electrical power requirement (fans plus

other equipment) for the process is 750 kWh, the same as that for the MC-based process for a KC-135 at OC-ALC, and the associated cost of utilities is $50 per KC-135 aircraft.

d. LARPS

Although details of the LARPS process utility requirements were not available at the time of this report's preparation, it is certain that the LARPS process will not require the same volume of building exhaust flow as the MC-based operation. Even so, the utility requirements were assumed to be the same as for depainting a KC-135 at OC-ALC using MC — $50 per aircraft.

e. Laser Stripping

Laser-based stripping will eliminate the need for the high flowrate ventilation required by chemical-based stripping operations. A typical laser system for potential application to strip KC-135 aircraft at OC-ALC is expected to consume 2 kW of power over the 160-hour stripping time, or 320 kWh. Building exhaust fan and other equipment requirements will be less than the 750 kWh assumed for MC stripping. When added to the laser system requirements, it is assumed that the total utility cost for laser stripping would be the same as that for MC depainting of a KC-135 at OC-ALC — $50 per aircraft.

4. PPE

All non-automated stripping processes will require the personnel attending or performing the stripping operations to wear more than nominal PPE. The cost for this PPE is the highest for chemical stripping methods. In the 1992 study noted above (2), the annual cost of PPE for depainting 37 KC-135 and 14 B-52 aircraft (total stripped surface of 564,400 ft^2) was estimated to be about $159,000, or $0.28/$ft^2$. The estimate included the labor costs involved for support and maintenance of PPE and the cost of new and replacement expendable items such as protective clothing and filters. This translates to a 1997 value of $0.34/$ft^2$, based on an annual four-percent cost escalation.

The level of PPE required for the MPW/BOSS process is less protective than that required for the MC-based process. However, the equipment used is similar to that required by the MC-based process and includes (see Section II) supplied air, masks, respirators, coveralls, rubber boots, and gloves. Therefore, the estimated PPE cost for the MPW/BOSS process is assumed to be the same as that for the MC-based operation — $0.34/$ft^2$. OC-ALC personnel have indicated that AF policy may dictate the use of the same level of PPE for BA as is currently used for MC. LARPS and the laser stripping processes will require negligible, or no, PPE.

a. MC-Based Stripping

At a rate of $0.34/ft^2, PPE costs for depainting are about $3,300 per KC-135 aircraft (9,600 ft^2 surface area), and $4,800 per B-52 aircraft (14,000 ft^2 surface area).

b. MPW/BOSS after Presoftening with BA

At a rate of $0.34/ft^2, PPE costs for depainting will be about $4,400 per C-130 aircraft (12,836 ft^2 surface area). Because the labor requirements for the C-141 are the same as those for the C-130, it is assumed that the PPE costs are also the same, at $4,400 per aircraft.

c. Two-Component BA Stripping

At a rate of $0.34/ft^2, PPE costs for depainting will be $3,300 per KC-135 aircraft (9,600 ft^2 surface area).

d. LARPS

The LARPS process will have negligible, if any, PPE costs.

e. Laser Stripping

The laser stripping process will also have negligible, if any, PPE costs.

5. Hazardous Waste Disposal

The sludge generated from depainting activities is typically allowed to accumulate in the depainting trenches while stripping is underway. Removal of this sludge in 55-gallon drums occurs periodically (see Section II). The removal rate among the different facilities varies from once a week to once every few months. Sludge from other depainting activities, such as depainting of parts, is combined with the sludge from aircraft depainting for removal. As a result, it proves difficult to accurately estimate the amount of sludge generated per aircraft by a given stripping process. The sludge is always disposed of as hazardous waste. Thus, even though the process may not use a hazardous-chemical stripper, the coating that has been stripped may contain hazardous constituents such as chromium. Current disposal costs are roughly $1.80/lb. SM-ALC environmental staff indicated that about two 55-gallon drums of sludge are produced per week at the KC-135 depainting facility. Assuming each drum contains about 500 lb of sludge, about 1,000 lb of sludge is produced from the depainting of one KC-135 aircraft (it takes roughly a week to prepare and depaint a KC-135 at SM-ALC), or 0.10 lb/ft^2 of aircraft depainted. In the absence of a better estimate on the amount of sludge produced per aircraft, it is assumed that 0.10 lb/ft^2 of sludge is generated by each of the MC, BA, and MPW/BOSS stripping processes. The LARPS system will produce little sludge, while the laser stripping process will produce none, although both processes generate stripped paint solids requiring disposal.

Wastewater generated from depainting processes is sent to the base IWTP for treatment. The cost of treatment is $6.00 per 1,000 gallons.

a. MC-Based Stripping

The amount of sludge generated at 0.10 lb/ft^2 is 960 lb for a KC-135 (9600 ft^2 surface area) and 1,400 lb for a B-52 (14,000 ft^2 surface area). The cost of disposal at $1.80/lb is $1,700 per KC-135 aircraft and $2,500 per B-52 aircraft. About 10,000 gallons of wastewater are generated per KC-135, and 20,000 gallons per B-52. Thus, the cost of wastewater treatment is $60 per KC-135 and $120 per B-52. The total cost of hazardous waste disposal and wastewater treatment is, therefore, about $1,800 per KC-135 and $2,600 per B-52.

b. MPW/BOSS after Presoftening with BA

The amount of sludge generated at 0.10 lb/ft^2 is about 1300 lb for a C-130 (12,836 ft^2 surface area) and 1,750 lb for a C-141 (17,425 ft^2 surface area). The cost for disposal is, thus, $2,300 per C-130 and $3,150 per C-141. About 41,000 gallons of wastewater are generated per C-130, and 56,000 gallons per C-141. The corresponding cost for wastewater treatment is about $250 per C-130 and $350 per C-141. The total cost of hazardous waste disposal and wastewater treatment is, therefore, $2,600 per C-130 and $3,500 per C-141.

c. Two-Component BA Stripping

Because the amount of sludge generated by the BA process is assumed to be about the same as that produced by the MC-based process, the total cost of hazardous waste disposal and wastewater treatment is the same — $1,800 per KC-135. This is a conservative estimate. The annual volume of BA used in a given facility for depainting is expected to be less than the corresponding amount of MC used. This is because only seven drums of the BA stripper are required to depaint Koroflex™-coated aircraft, in comparison to the MC-based stripper of which up to 28 drums are required.

d. LARPS

There is no sludge generated with the LARPS process although stripped paint solids require disposal. Water used to strip can be recycled many times over, after filtration to take out the removed paint chips and fine solids. It is assumed here that the total cost of hazardous waste disposal and wastewater treatment will be about $900 per KC-135, which is half the corresponding costs associated with the MC-based process.

e. Laser Stripping

The laser stripping process will generate some quantity of solid waste (stripped paint solids) per aircraft. Typically, the dust generated from the stripping process will be collected on filters needing to be periodically disposed of as hazardous waste. The total cost of hazardous waste disposal is assumed to be the same as for the LARPS process — $900 per KC-135 aircraft.

6. Training and Occupational Medical Requirements

Required training for depainting process workers includes safety training (12 hr/yr/employee), hazardous chemical usage refreshers (8 hr/yr/employee) and respirator fit-tests (4 hr/yr/employee). Occupational medical costs include the annual physicals required by medical surveillance programs (8 hr/yr/employee), and depainting process related time off. Time off may be due to absence, or inability to work while wearing PPE. Medical costs may also include those to process medical claims related to occupational factors.

The 1992 study by Rankin and Mendelsohn (2) estimated the annual cost for all training for depainting process workers to be $41,344. This estimate was based on the training needs for 76 personnel employed in Building 2122, the MC-based depainting facility at OC-ALC. Thus, the cost of training in 1992 was $544 per person. The 1997 cost of training is therefore assumed to be $661 per person, based on a four-percent annual escalation in costs. The annual training cost tends to be a fixed cost that is not affected by the number of aircraft depainted. However, the number of personnel requiring training depends on the size of the aircraft depainted. It is reasonable to assume that, regardless of the type of stripping process used, all facility floor-personnel involved with the stripping process will need to complete the training.

The Rankin and Mendelsohn study (2) also estimated the annual medical costs related to occupational factors. The costs for loss of time incurred due to depainting activities at OC-ALC's Building 2122 was $50,090. Of this, only about 50 percent was estimated to be related to aircraft depainting, and the rest related to activities such as parts depainting. This implies that the annual medical cost for aircraft depainting alone was $25,045. This cost should be related to the number of aircraft depainted (total area depainted). According to the report, 564,400 ft^2 of aircraft area (34 KC-135s and 14 B-52s) were depainted in 1992. Therefore, the corresponding medical costs were $45 per 1,000 ft^2. The 1997 value, using an annual four-percent cost escalation, is $55 per 1,000 ft^2. Because MPW/BOSS and the two-component BA process are both assumed to employ the same PPE as the MC process, it is reasonable to assume that the medical costs ($55/1,000-$ft^2$) for these two processes are the same as well. These costs are not

considered for the LARPS and laser stripping processes because stripping chemicals and associated high-level PPE are not used.

a. MC-Based Stripping

For the KC-135 aircraft, seven persons per shift are involved in the paint stripping process. At three shifts per day, with an assumed 10-percent annual turnover of personnel, the cost of training is about $15,200 per year for the paint-stripping crew. At OC-ALC, 50 KC-135 aircraft are depainted per year, on average. The cost of training per aircraft at OC-ALC is, therefore, about $300. At SM-ALC, about 20 KC-135 aircraft per year are depainted. The cost of training per aircraft at SM-ALC is, thus, about $800 per aircraft.

For the B-52 aircraft, 10 persons per shift are involved in the stripping process. Both B-52s and KC-135s are depainted in Building 2122 at OC-ALC, and ostensibly could be stripped by a common set of workers. However, for this analysis, it is assumed that a different set of personnel are used to depaint B-52s. At three shifts per day, and a 10-percent annual turnover of personnel, the cost of training for this separate B-52 depainting crew is about $21,800 per year. At OC-ALC, 18 B-52 aircraft are targeted for depainting per year. The cost of training is, therefore, $1,200 per aircraft.

The medical costs associated with paint-stripping, at $55/1,000 ft^2, are $500 per KC-135 (9,600 ft^2 surface area) and $800 per B-52 (14,000 ft^2 surface area).

b. MPW/BOSS after Presoftening with BA

Depainting a C-130 and a C-141 both require 8 personnel per shift. Communications with OO-ALC and WR-ALC personnel indicated that this process is only a single-shift operation. Assuming a 10-percent annual personnel turnover rate (i.e., nine personnel require training), training costs are about $5,900 per year.

Approximately 21 C-141 aircraft are depainted per year. The corresponding annual training costs are, thus, about $300 per C-141. Over a 10-month period in 1996, 18 C-130 aircraft were depainted at WR-ALC; the cost of training is, again, about $300 per aircraft. Information from OO-ALC indicated that about 50 C-130 aircraft are depainted there per year. The corresponding cost of training is, therefore, about $100 per C-130 at OO-ALC.

At $55/1,000 ft^2, medical costs are about $700 per C-130 and $1,000 per C-141.

c. Two-Component BA Stripping

Information obtained from OC-ALC, where the BA stripping process is being tested, suggests that training and medical costs associated with this process are likely to be similar to those associated with the current MC-based operation. The cost of training at OC-ALC

associated with a two-component BA stripping process is, therefore, expected to be $300 per KC-135 and $1,200 per B-52 (assuming that the same number of aircraft are depainted per year of each type). The medical costs for stripping are expected to be $500 per KC-135 and $800 per B-52.

d. LARPS

The personnel involved with the LARPS process are also expected to need the same level of training as workers in the rest of the depainting facility. In the future, there may be a reduction in the training level if the entire facility converts to the LARPS system. For now, however, it is assumed that the required level is the same as that needed for the MC-based operation. Therefore, the cost of training at OC-ALC associated with the LARPS process is expected to be $300 per KC-135 and $1,200 per B-52 (again assuming that the same number of each type of aircraft are depainted per year as with MC currently). The medical costs related to LARPS paint stripping are assumed to be zero.

e. Laser Stripping

The personnel involved with the laser stripping process will also likely have to undergo the same level of training as workers in the rest of the facility, at least until an automated system for all paint-stripping activities is implemented facilitywide. For now, it is assumed that the required level is the same as that needed for the MC-based operation. Therefore, the cost of training at OC-ALC associated with the laser stripping process is expected to be $300 per KC-135 and $1,200 per B-52 (once again assuming that the same number of aircraft of each type are depainted per year as with MC currently). The medical costs related to laser paint stripping are assumed to be zero.

C. OPERATING COST SUMMARY

Tables 11 through 15 summarize the operating costs for each of the five paint stripping processes discussed in Section III.B. Information in the tables is discussed in the following subsections.

1. MC-Based Stripping

Table 11 summarizes the operating cost data for the MC-based depainting process. The data in the table show that the cost of depainting a KC-135 at OC-ALC is $28,550/aircraft, while it is $30,100/aircraft at SM-ALC. The cost differences arise from differences in the quantities of stripper used at the two ALCs, and corresponding differences in labor requirements. The cost of depainting a B-52 at OC-ALC is $36,150. The operating cost per ft^2 of aircraft depainted using MC ranges from $2.60/ft^2 to $3.10/ft^2. These depainting costs are based on

TABLE 11. OPERATING COSTS FOR THE MC-BASED DEPAINTING PROCESS.

Aircraft Type	KC-135	B-52	KC-135
Location	OC-ALC	OC-ALC	SM-ALC
	$/Aircraft		
Raw materials	4,600	4,600	3,100
Labor	18,000	22,100	20,600
Utilities	50	50	20
PPE	3,300	4,800	3,300
Hazardous waste disposal and wastewater treatment	1,800	2,600	1,800
Training	300	1,200	800
Medical	500	800	500
Total Cost ($)[a]	28,550	36,150	30,100
Normalized Cost ($/ft^2)	3.00	2.60	3.10

[a]Rounded to the nearest $50.

current procedures and do not include the costs of any emission controls that would be required to meet the aerospace NESHAP. The projected costs of NESHAP-required controls will be quite significant, as discussed in Section VII.

2. MPW/BOSS after Presoftening with BA

Table 12 summarizes the operating cost data for the MPW/BOSS depainting process. The data in the table show that the cost of depainting a C-130 at WR-ALC is $26,500, while at OO-ALC it is $30,000. This difference is due largely to the different quantities of the stripping agents used at the two ALCs. At OC-ALC, more BA presoftener and less BOS are used compared to the practice followed at OO-ALC. The cost of depainting a C-141 at WR-ALC is $26,300. The operating cost per ft^2 of aircraft depainted using MPW/BOSS ranges from $1.50/ft^2 to $2.30/ft^2.

3. Two-Component BA Stripping

Table 13 summarizes the operating cost data for depainting a KC-135 using the two-component BA stripping process. As indicated, these costs are $35,300 per KC-135, or $3.70/ft^2.

TABLE 12. OPERATING COSTS FOR THE MPW/BOSS DEPAINTING PROCESS.

Aircraft Type	C-130	C-141	C-130
Location	WR-ALC	WR-ALC	OO-ALC
	$/Aircraft		
Raw materials	5,900	5,300	10,100
Labor	11,800	11,800	11,800
Utilities	20	20	20
PPE	4,400	4,400	4,400
Hazardous waste disposal and wastewater treatment	2,600	3,500	2,600
Training	100	300	300
Medical	700	1,000	700
Total Cost ($)[a]	25,500	26,300	29,900
Normalized Cost ($/ft^2)	2.00	1.50	2.30

[a]Rounded to the nearest $50.

TABLE 13. OPERATING COSTS FOR THE TWO-COMPONENT BA DEPAINTING PROCESS.

Aircraft Type	KC-135
Location	OC-ALC
	$/Aircraft
Raw materials	11,700
Labor	15,500
Utilities	50
PPE	4,800
Hazardous waste disposal and wastewater treatment	1,800
Training	500
Medical	800
Total Cost ($)	35,150
Normalized Cost ($/ft^2)	3.70

Comparing these costs to those in Tables 11 and 12 shows that the BA process is more expensive than the MC-based and the MPW/BOSS processes.

4. LARPS

The operating cost for depainting a KC-135 using the LARPS system is $10,250, as summarized in Table 14. The normalized cost is $1.10/ft^2. These projected costs suggest that depainting with a LARPS system will incur considerably lower operating costs than the three chemical stripping processes.

5. Laser Stripping

The operating cost for depainting a KC-135 using the laser stripping system is projected to be about $11,750 as summarized in Table 15. The normalized cost is $1.20/ft^2. These projected costs are about the same as those for the LARPS process, which, in turn, are considerably less than those for the chemical stripping processes. It should be noted, however, that cost-effective laser-based stripping technologies for large aircraft frames require further development.

D. STRIPPING RATE AND FLOW TIME

Operating costs are one measure of the potential attractiveness of a given depainting process. However, another measure is the time required to complete the process. The time period during which an aircraft is removed from service to undergo depainting and repainting is time that aircraft cannot fulfill its mission. Clearly, then, a process that minimizes the out-of-service time required to complete depainting has benefits over the other, more time-consuming processes. Shorter out-of-service time can offset an operating cost disadvantage.

Two measures of the time required to complete a given depainting process are commonly used. The first, termed *stripping rate,* is defined here to be the aircraft surface area depainted per labor hour. The second measure, termed *flow time,* is the time period that starts when an aircraft enters a depainting facility and ends when the depainted aircraft leaves the facility fully prepared to be repainted. Flow time takes into consideration the time needed to prepare the aircraft for depainting, the time required to strip the aircraft, and the time required for any needed post-stripping work. Thus, it is a more-complete measure of the time period during which an aircraft is unavailable for service. In the following subsections, process stripping rates and associated flow times are discussed for the five depainting processes under consideration.

1. MC-Based Stripping

The stripping rates for KC-135 and B-52 aircraft at OC-ALC and SM-ALC are summarized in Table 16. The stripping rate for the KC-135 is 24.5 ft^2/hr at OC-ALC and 19.0

TABLE 14. OPERATING COSTS FOR THE LARPS DEPAINTING PROCESS.

Aircraft Type	KC-135
Location	OC-ALC
	$/Aircraft
Raw materials	100
Labor	8,900
Utilities	50
PPE	0
Hazardous waste disposal and wastewater treatment	900
Training	300
Medical	0
Total Cost ($)	10,250
Normalized Cost ($/ft^2)	1.10

TABLE 15. OPERATING COSTS FOR THE LASER DEPAINTING PROCESS.

Aircraft Type	KC-135
Location	OC-ALC
	$/Aircraft
Raw materials	0
Labor	10,500
Utilities	50
PPE	0
Hazardous waste disposal and wastewater treatment	900
Training	300
Medical	0
Total Cost ($)	11,750
Normalized Cost ($/ft^2)	1.20

TABLE 16. STRIPPING RATES FOR THE MC-BASED PROCESS.

Aircraft Location	KC-135 OC-ALC	B-52 SM-ALC	KC-135 OC-ALC
Stripping hours	392	480	504
Aircraft area (ft^2)	9,600	14,000	9,600
Stripping rate (ft^2/hr)	24.5	29.1	19.0

ft^2/hr at SM-ALC. The stripping rate at SM-ALC is lower because more labor hours are used (though less stripping solvent) to strip the aircraft at this facility. The stripping rate at OC-ALC for the B-52 is 29 ft^2/hr.

The flow time for both aircraft types at both facilities is the same, six to seven working days.

2. MPW/BOSS after Presoftening with BA

The stripping rate for a C-130 aircraft at both OO-ALC and WR-ALC is 50 ft^2/hr; 256 labor hours are required to strip 12,836 ft^2 of aircraft area. The stripping rate for a C-141 at WR-ALC is 68 ft^2/hr; 256 labor hours are required to strip 17,425 ft^2 of aircraft area. The flow time for both aircraft types at both facilities is the same, between eight and nine days.

3. Two-Component BA Stripping

The stripping rate for the KC-135 at OC-ALC is 28.6 ft^2/hr; 336 labor hours are required to strip 9,600 ft^2 of aircraft area. The average flow time is expected to be the same as that for the MC-based process, between six and seven days.

4. LARPS

The stripping rate for the LARPS process is fixed by the process rate itself, and not by the labor hours devoted to it. The equipment currently installed at OC-ALC is capable of a stripping rate of 150 ft^2/hr. Based on this, the flow time is expected to be four to five days for a KC-135.

5. Laser Stripping

The stripping rate for the laser process is also fixed by the process itself. The laser stripping rate, which is generally set by the laser power and removed coating thickness, is typically 2 $ft^2/min/mil/kW$. For a 2-kW laser, this translates to 60 ft^2/hr to remove a 4-mil-thick

coating (a typical coating thickness). At this stripping rate, the flow time to depaint one KC-135 is expected to be between seven and eight days.

E. CONVERSION COSTS

As mentioned earlier, one of the main objectives of this project was to determine the cost of converting an existing MC-based operation into one using an alternative process. Because the largest MC-based operation is the KC-135 depainting facility at OC-ALC, it was chosen as the representative process (baseline case) for conversion estimates. Table 17 summarizes the operating costs for depainting a KC-135 at OC-ALC using each of the five technologies under consideration. The information in Table 17 was taken from the discussion in Section III.C, with the following additional assumptions:

- For the MPW/BOSS process, the stripping rate and the depainting cost were assumed to be the average of the three cases outlined in Section III.C (the C-130 at OO-ALC and WR-ALC, and the C-141 at WR-ALC)
- In using the MPW/BOSS process to depaint the KC-135, it was assumed that a crew of seven would be used

As shown in Table 17, the process operating cost is the lowest for the LARPS process, at \$10,560 per aircraft. The laser-based process is next at \$11,500 per aircraft. This is followed by the MPW/BOSS process, at \$18,240 per aircraft. The two-component BA process has the highest operating cost, at \$35,250 per aircraft. However, the operating cost of the MC-based process, currently \$28,800 per aircraft, will increase significantly with the addition of the emission control equipment that will be required to meet the aerospace rework NESHAP. These costs are discussed in Section VII.

Finally, the potential change in capacity (the increase/decrease in the number of aircraft depainted in the specified time period) compared to the baseline (MC depainting) case was estimated based on the flow time required by each process. The flow time, as noted above,

TABLE 17. SUMMARY OF PROCESS OPERATING COSTS FOR A KC-135.

Process	MC (Baseline)	MPW/BOSS	BA	LARPS	Laser
Depainting cost ($/ft^2)	3.0	1.9	3.7	1.1	1.2
Depainting cost ($/aircraft)	28,800	18,240	35,520	10,560	11,520

consists of the total time required for pre-stripping, stripping, and post-stripping activities. The stripping time for each technology was determined for the KC-135 case. The flow time for the MC-based process includes about 2 days each for pre- and post-stripping activities (4 days total). The same amount of pre- and post-stripping time (4 days total) was assumed to be needed for the MPW/BOSS and BA processes. For the LARPS and laser processes, the pre- and post-stripping time was assumed to be 1.5 days total.

The potential changes in capacity for each process are summarized in Table 18. As shown in the table, up to 50 percent more aircraft can potentially be depainted in a given time period by LARPS than by the baseline (MC) process. The estimated increase using MPW/BOSS is 26 percent; with BA it is 5 percent. The laser process shows a decrease in the capacity of about 19 percent. However, the capacity for the laser process can be improved by increasing the number of lasers (or increasing laser power) with only a slight increase in the operating cost. The overall cost impact of this possibility is discussed in Section VII.

TABLE 18. POTENTIAL CHANGE IN CAPACITY WITH ALTERNATIVE TECHNOLOGIES FOR THE KC-135.

Process	MC Stripping (Baseline)	MPW/BOSS	Two-Component BA	LARPS	Laser Stripping
Stripping rate (ft^2/hr)	24.5	56	28.6	150	60
Stripping time (hr)	392	171	336	64	160
Paint stripping crew (no. of persons)	7	7	7	3	3
No. of shifts (days)	7 (2.3)	3 (1.0)	6 (2.0)	8 (2.7)	19 (6.3)
Average flow time (days)	6.3	5	6	4.2	7.8
Increased in number of aircraft depainted (%)	0	26	5	50	-19

F. REFERENCES FOR SECTION III

1. Wool, M., "Environmentally Friendly Paint Stripping of Aerospace Composites Using a Computer-Controlled Laser," Proceedings of the First Annual Joint Service Pollution Prevention Conference and Exhibition, San Antonio, Texas, August 1996, p. 363.

2. Rankin, D. S., and Mendelsohn, C. R., "Pollution Prevention, Investment Decision Model to Assess Financial Feasibility for Application to Air Force Processes," Thesis, AFIT/GEE/ENV/92S-15, Air Force Institute of Technology, Wright–Patterson AFB, Ohio, 1992.

SECTION IV

EMISSION CONTROL TECHNOLOGIES FOR METHYLENE CHLORIDE

A. EMISSIONS OF METHYLENE CHLORIDE FROM THE DEPAINTING PROCESS

A large quantity of MC is used during aircraft frame depainting at OC-ALC and SM-ALC (see Section II.B.1). For example, as noted in Section II, paint stripping of a Koroflex™-coated KC-135 can use up to 28 55-gallon drums (15,400 lb) of the MC-based stripper. Stripping a polyurethane/ epoxy-coated aircraft can use up to 15 55-gallon drums (8,250 lb) of the MC-based stripper. On average, the MC content of the stripper is 50 percent by weight. Table 19 summarizes the estimated MC emissions on this basis from a facility that ventilates 440,000 cfm of exhaust air during the stripping operation, as does Building 2122 at OC-ALC.

During the depainting of an aircraft, the MC stripper is applied in as many as five batches. As a result, MC emissions from the depainting facility are intermittent. If the MC emissions throughout a paint-stripping operation were measured at the ventilation stack of the hangar, the emission profile over the stripping period would be similar to that shown in Figure 1. In one test study conducted to estimate MC emissions during the stripping of an E-3 aircraft in Building 2280

TABLE 19. ESTIMATION OF MC EMISSION RATES.

Parameter	KC-135 Aircraft at OC-ALC: Epoxy/ Polyurethane-Coated	KC-135 Aircraft at OC-ALC: Koroflex™-Coated
Exhaust flowrate (cfm)	440,000	440,000
Typical maximum amount of stripper used (lb)	8,250	15,400
Maximum amount of MC (at 50%) (lb)	4,125	7,700
Emission Estimates (assuming 100% evaporation)		
1a. Over a 48-hour period during which stripping takes place (lb/hr)	86	160
1b. Average exhaust concentration (ppmv)	15	28
2a. Per application (lb/hr) (at 3 hours total dwell time and 3 applications for complete stripping)	458	856
2b. Average exhaust concentration (ppmv)	80	150

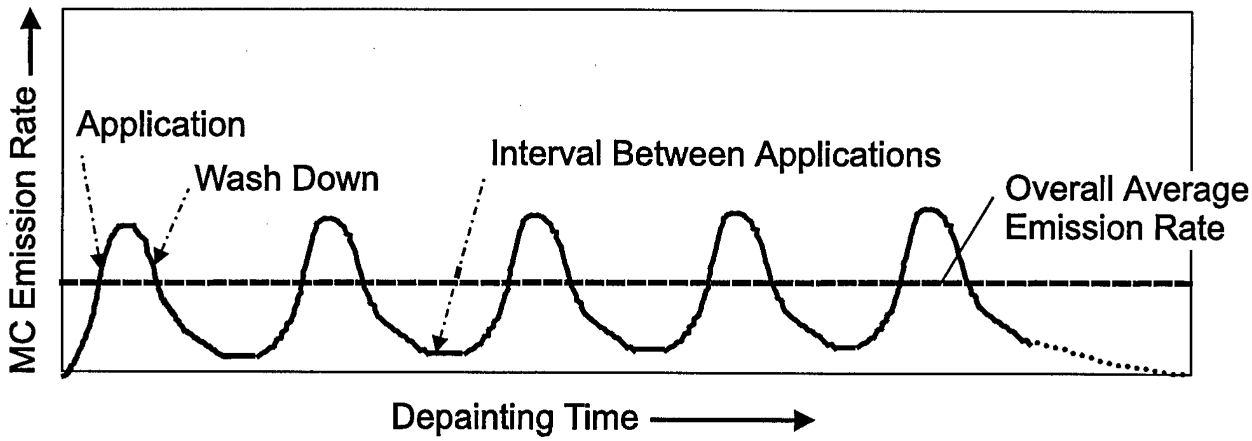


Figure 1. Typical MC Emission Profile During Depainting of an Aircraft Frame.

at OC-ALC, 2,913 lb of MC stripper formulation were applied during the first 1-1/2 hours of the operation (1). Measurements at the building ventilation exhaust stack indicated that 1,057 lb of MC were emitted over this period and that the stack flowrate was 60,000 scfm. The entire measurement period lasted 6-1/2 hours, and the maximum MC concentration measured during this period was 717 ppmv. These data indicate that the maximum MC emission rate was 595 lb/hr. The total amount of MC emitted from the stack during the entire stripping process, which lasted for about 9-1/2 hours, was estimated to be 1,400 lb, giving an average emission rate of 147 lb/hr. This implies that only 48 percent of the MC applied was emitted through the stack. Measurements for MC concentrations were not performed on the wash water, the other major discharge route for MC. If the remainder of the MC was indeed discharged with the wash water, then the discharge rate of MC in the wastewater stream would have been about 159 lb/hr for the 9.5-hour period.

B. EMISSION CONTROL TECHNOLOGIES FOR METHYLENE CHLORIDE

MC emissions from large depainting hangars can be classified as low-concentration, high-flowrate emissions. Control of emissions in this class is typically quite expensive. Technologies for the control of such low-concentration, high-flowrate emission streams containing VOCs and organic HAPs are in one of two broad categories: capture and VOC treatment. VOC treatment

can include either recovery or destruction techniques. Table 20 gives an overview of the available technologies for controlling VOCs and HAPs.

A 1995 EPA report (2) identifies 25 control devices in existence in the United States for treating low-concentration, high-flowrate organic vapor streams. The flowrates of the gas streams treated ranged from 70,000 cfm to 600,000 cfm, and organic vapor concentrations ranged from 10 to 300 ppmv. Table 21 gives a breakdown of these installations. Of the 25 installations, 13 were used to treat paint and solvent vapors. As can be seen from the information in Table 21, the most-common treatment technology is the regenerative thermal oxidizer, followed by capture with a concentrator combined with thermal destruction. None of the 25 installations comprising the listing in Table 21 treated any known quantities of MC. However, the technologies in the listing represent generic VOC control approaches that would directly apply to the control of MC. The following subsections describe these control technologies in more detail, and discuss their applicability, commercial availability, and associated control costs.

To address control costs, we contacted a number of control-process vendors to obtain cost information on their offered technologies. However, very few of them provided written cost information. Thus, the order-of-magnitude costs discussed in the following subsections were developed based on vendor interviews and review of the literature on VOC/HAP control, and by using the control-cost manual developed for EPA's Office of Air Quality Planning and Standards (OAQPS) (3). These cost indices for various air-pollution-control technologies, first developed in 1986, are updated every quarter and published (4) along with other established industrial

TABLE 20. GENERIC TECHNOLOGIES FOR THE CONTROL OF VOCs AND HAPs.

Capture	
Adsorption	Activated carbon, polymers, and zeolites
Absorption	Liquid absorption
Treatment	
Destruction	Thermal oxidation UV/ozone oxidation Biotreatment
Recovery	Refrigerant condensation Compression condensation Cryogenic recovery

TABLE 21. SUMMARY OF LOW-CONCENTRATION, HIGH-FLOW TREATMENT INSTALLATIONS IN THE UNITED STATES.

Device Type	Number of Installations	Flowrate Range (scfm)	Concentration Range (ppmv)
Regenerative thermal oxidizer	11	80,000–500,000	100–300
Concentrator and thermal oxidizer	7	135,000–600,000	60–100
Concentrator/desorb and recover (rotary zeolites and activated carbon)	4	135,000–320,000	25–100
Mist scrubbers	2	70,000–75,000	N.A.[a]
Liquid absorber	1	90,000	10

[a]N.A. = Not available.

equipment price indices. The cost-estimating spreadsheets, and vendor quotes (wherever available), are included in Appendix C. The estimated prices are based on MC emission rates similar to those given in Table 19, assuming an annual operation of 5,000 hours.

1. MC Capture Technologies

Adsorption and absorption techniques are commonly used to capture organic vapor contaminants from gas streams. Adsorption of organic vapors is typically accomplished using activated carbon, zeolites, and polymers. Absorption is typically achieved by placing the gaseous contaminant into contact with an aqueous solvent stream. Absorption methods for MC capture from low-concentration, high-flowrate gas streams are not cost effective, largely because MC is, at most, sparingly soluble in aqueous solution. As a result, absorption will not be considered in this report as a realistic option for application to depainting facility exhaust.

a. Carbon Adsorbers

Carbon adsorption is quite commonly used as a technology to capture organic vapors. Activated carbon is the standard adsorbent. The adsorptive capacities of a typical activated carbon for several organic HAPs are listed (5) in Table 22. The data in the table show that the adsorptive capacity of activated carbon for MC is relatively low compared to its capacity for other common organic pollutants. On the basis of the MC data in Table 22, at least 154,000 lb of activated carbon would be required to capture 7,700 lb of MC from a gas stream containing 100 ppmv of MC.

TABLE 22. ADSORPTION CAPACITY OF ACTIVATED CARBON.

Compound	Equilibrium Adsorption Capacity at 60°F, 1 atm (wt%)	
	Gas Stream Concentration	
	100 ppmv	1,000 ppmv
Benzene	20	30
Carbon tetrachloride	33	50
Methyl ethyl ketone	15	28
Methylene chloride	5	12
Phenol	45	55
Tetrachloroethylene	40	55
Toluene	17	25
Ethyl benzene	28	36
Xylene	25	35

The carbon adsorption capacity for contaminant organics is also affected by the concentration of the contaminant in the gas stream. As the concentration of the organic contaminant decreases, adsorption becomes less efficient. However, for organic contaminant concentrations above 100 ppmv, carbon adsorbers can achieve control efficiencies of at least 95 percent, and capture efficiencies of up to 97 percent are not uncommon.

Examples of the control-process vendors that indicated experience with capturing MC using adsorption technologies include Vara International, Durr Industries, Met-Pro, and Reeco; however, this is only a partial list, and other vendors may provide similar equipment. Carbon adsorption systems come in various designs, including fixed-bed adsorbers, rotary concentrators, moving-bed adsorbers, and fluidized-bed adsorbers. Figures 2, 3, and 4 are process schematics of typical carbon-adsorption-based VOC-treatment systems. For high-flowrate processes (gas flows greater than 100,000 cfm), the cost of a carbon adsorption system is on the order of $10/cfm in capital investment, and $1.60/cfm in annual operating cost.

There are a number of advantages associated with using carbon adsorption systems. For example, there is a substantial experience base with carbon adsorbers, and even some experience with MC. These systems can be quite efficient, 95 to 97 percent or higher, as noted above. A figure of merit for an adsorption system is its flow reduction ratio. This is defined

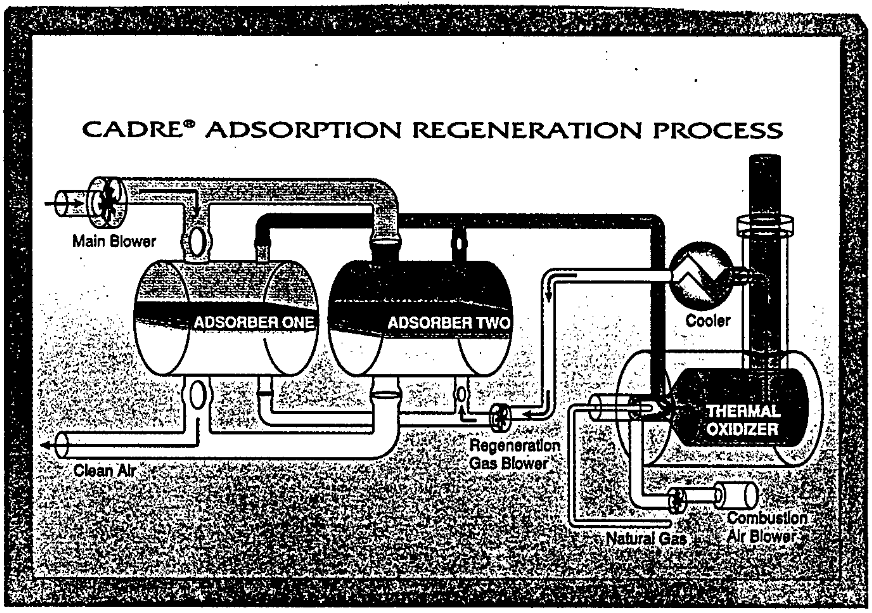


Figure 2. Example Fixed-Bed Carbon Adsorption VOC Treatment System — CADRE™ Adsorption Regeneration Process. (System is shown for illustrative purposes only, and not as an endorsement of a specific vendor.)

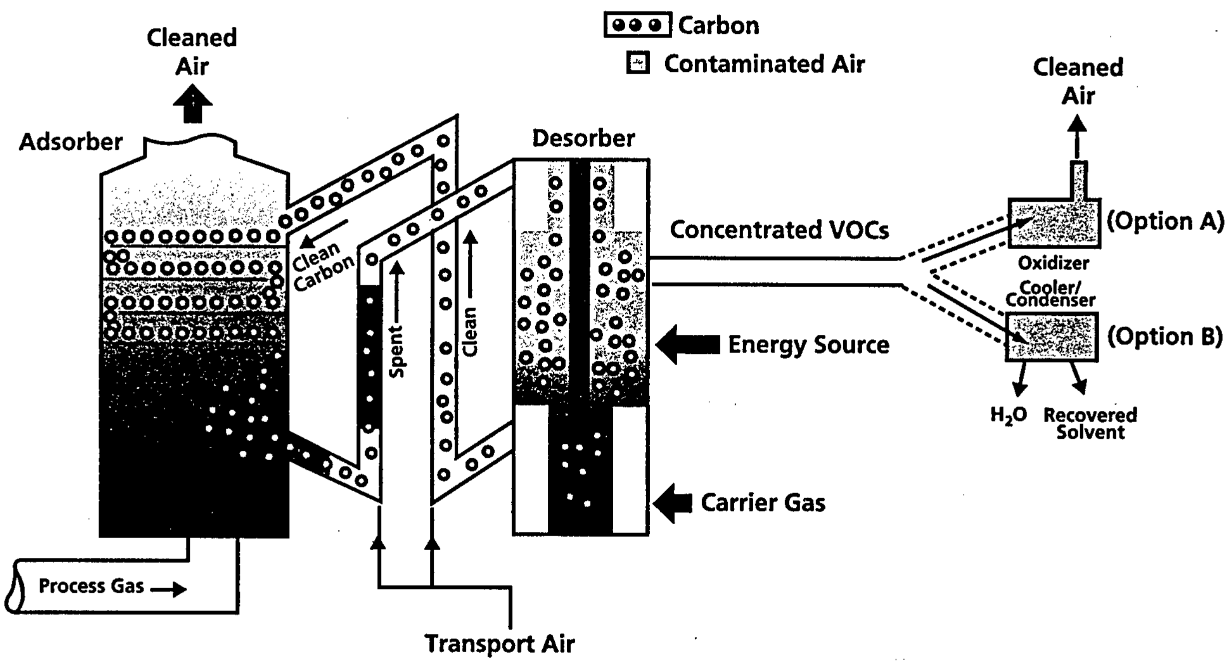
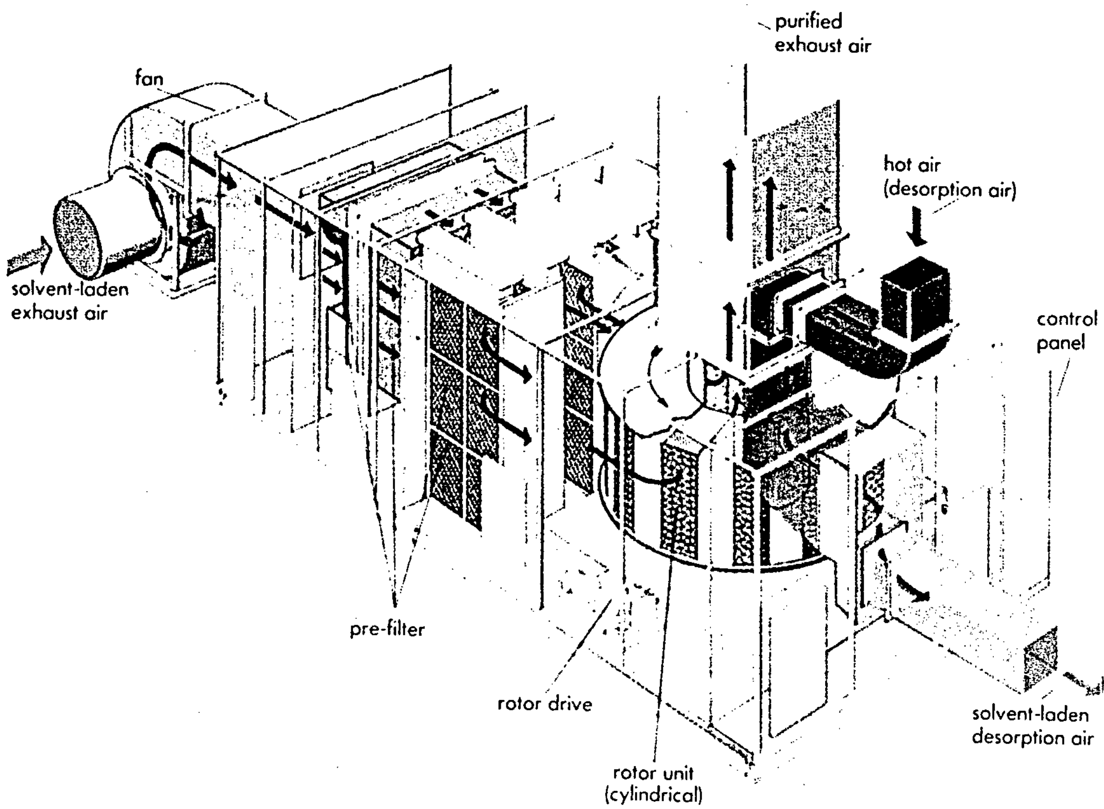
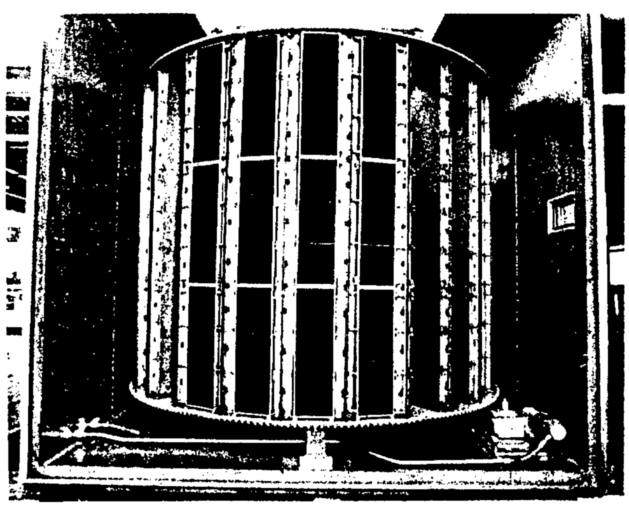


Figure 3. Example Moving-Bed Carbon Adsorption VOC Treatment System. (System is shown for illustrative purposes only, and not as an endorsement of a specific vendor.)





Rotating cylinder housing adsorbing elements.

Figure 4. Example Rotary Concentrator VOC Treatment System. (System is shown for illustrative purposes only, and not as an endorsement of a specific vendor.)

as the ratio of the gas stream discharge flowrate during the regeneration (collected organic desorption) of the adsorber to the gas stream flowrate being treated. Typical fixed-bed carbon adsorbers have flow reductions in the 40:1 range. The resulting contaminant gas stream leaving the adsorber during regeneration thus becomes more of a high-concentration, low-flowrate stream that can, in turn, be treated more efficiently and at lower costs. The Reeco FluiSorb™ system,[1] a moving-bed carbon adsorption system using proprietary spherical carbon granules for adsorption, is claimed, by Reeco, to achieve flow reductions of as much as 10,000:1.

There are also several disadvantages in using carbon adsorption systems. MC-based depainting processes are intermittent in nature (see Figure 1). The carbon control system typically requires lengthy start-up and shutdown procedures. For example, prior to shutting down a fixed-bed carbon system, a desorption cycle must be performed so that the risk of fire during restart of the system is minimized. In fact, the risk of fire in carbon bed systems, especially those adsorbing certain ketones used as solvents, is a common concern. Rotary carbon adsorption units must also be completely desorbed before being shut down. The desorption cycle typically requires steam, heated air, or combustion gas, which adds to the system's operating costs. Depending on the process controlled, carbon beds need to be completely replaced once every 3 to 5 years. This replacement cost can be quite significant.

b. Zeolitic Adsorbers

Zeolites are hydrated alkali aluminosilicates. Hydrophobic zeolites are commonly used to adsorb VOCs and organic HAPs from contaminated air streams. Recent developments in zeolite technology have resulted in materials that repel water (hydrophobic), which in turn increases their adsorption capacity. Zeolites have greater adsorption capacities than carbon for low gas-stream inlet concentrations, although at high concentrations of organic contaminants, carbon has more capacity. Most zeolitic adsorption systems for VOC capture are commercially available as rotary concentrators. In these systems, the low-concentration, high-flowrate air stream is drawn through a honeycomb (typical configuration in these applications) zeolite rotor in which the VOCs are removed. After passing through the rotor, the clean air is discharged or treated further. Collected VOCs are subsequently desorbed in a regeneration sector using a stream of heated air (typically between 400° and 600°F). The heated-air flowrate through the

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[1] FluiSorb Fluidized Bed Concentrator, technical literature, Reeco, A Research Cottrel Company, February 1997.

regeneration sector is generally 10 percent of the flowrate of the process air stream treated. Standard flow reduction ratios are therefore 10:1 for rotary zeolite adsorbers.

Durr Industries, Munters Corporation, and Alzeta Corporation are some of the vendors of integrated VOC-control systems that use zeolitic rotary concentrators. The cost of a standalone rotary concentrator was not provided by any of the above vendors, as their usual offerings are integrated treatment systems. Telephone conversations with the Durr representative[2] indicated that the cost to control high-flowrate streams using zeolitic concentrators is comparable to the cost of control with carbon adsorption. Figure 5 is a schematic of a commercially available VOC treatment system that uses a zeolitic rotary concentrator.

Zeolite concentrators have several advantages. For example, they present less of a fire hazard than carbon adsorbers. In addition, zeolites, in general, have greater adsorption capacities than carbon for water-insoluble organic compounds, such as MC, at low organic contaminant concentrations in the process gas streams.

Zeolites also have disadvantages. For example, zeolites are more expensive than activated carbon, at $7 to $25/lb compared to $2/lb for carbon. In addition, a specially tailored zeolite may be required to effectively treat MC. Both factors tend to make zeolite rotors quite expensive to replace. The serviceable lifetime of a zeolitic rotary concentrator is comparable to that of an activated-carbon bed. However, there is concern in the industry over control process breakdown due to mechanical damage to the rotary wheels.

c. Polymer Adsorption

Several special polymers that adsorb organic vapors are currently available. One such polymer adsorbent, manufactured by DOW Chemical Company, is marketed under the trade name DOWEX *OPTIPORE* V502™. Vendor literature indicates that at low concentrations, the adsorption capacity of this DOW polymer is similar to that of activated carbon. However, DOW claims that the chemical resistance and the mechanical strength of the polymer are greater than those of both activated carbon and granulated zeolite, making it a better candidate for moving-bed adsorbers. Moving-bed adsorbers typically require much less adsorbent than stationary beds; however, they are typically more costly to build and operate.

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[2] Communications with Mark Hill, Representative for Durr Industries, September 1996, Tel.: (415) 669-1111.

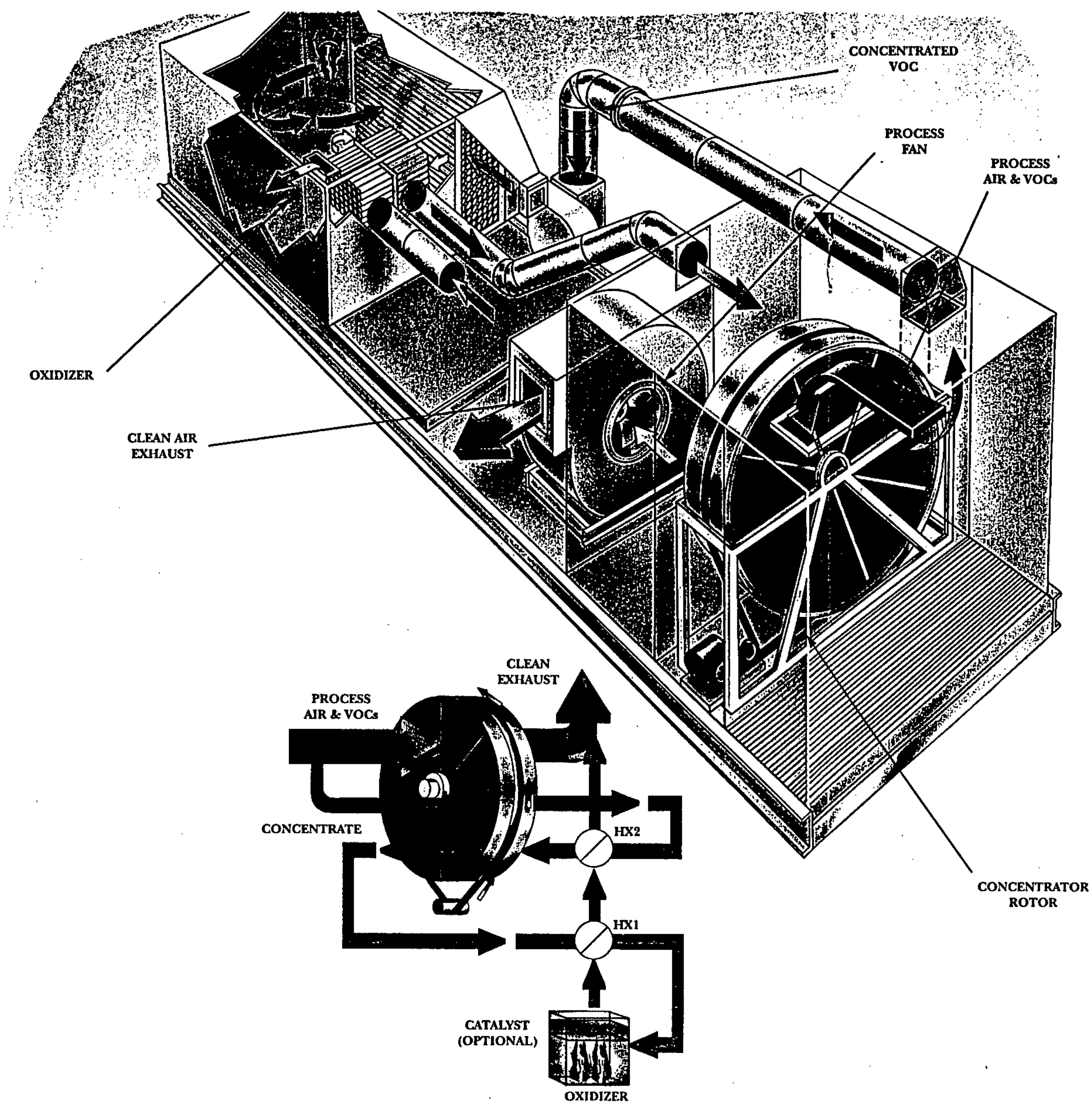


Figure 5. Example Rotary Concentrator VOC Treatment System. (System is shown for illustrative purposes only, and not as an endorsement of a specific vendor.)

Another commercial VOC-treatment system that uses polymer adsorption technology is the MAG 10000™ system marketed by Fenix Systems, Ltd. This system consists of a moving polymer bed that is regenerated by microwave heating. Figure 6 is a schematic showing an example application of this technology. A typical MAG 10000™ system is capable of handling gas flows up to 10,000 cfm, and costs about $2M ($40/cfm). The price includes recovery of the collected VOC by a condensation system. The operating cost was quoted to be about $17/hr, at 2,500 hours of operation annually, which did not include the cost of MC disposal.

Polymer adsorption systems are not yet considered to be established technology for the treatment of low-concentration, high-flowrate gas streams. Thus, substantial field testing will be required before such a system is recommended for controlling MC from depainting facilities.

2. Thermal Oxidation

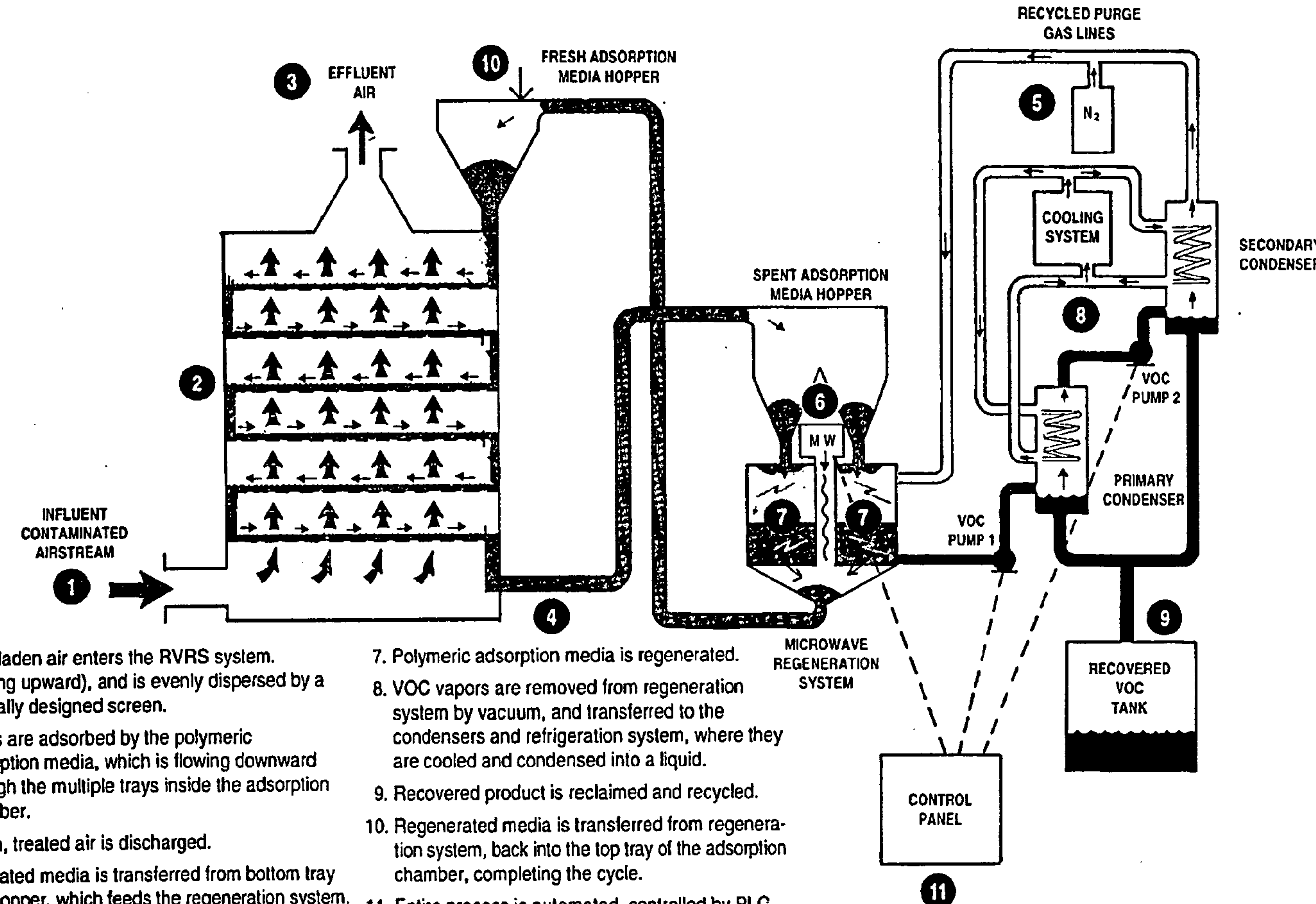
Thermal oxidation is the most common VOC-treatment technology when recovery is either not an option or not an economical option. Thermal oxidation systems destroy organics at high temperatures, usually between 1,400° and 1,850°F. Chlorinated organics such as MC typically require temperatures of greater than 1,600°F for essentially complete destruction in the absence of an oxidation catalyst. Substantially reduced destruction temperatures are possible with catalytic systems, which are becoming increasingly more common. Catalytic oxidation systems typically operate at between 650° and 950°F. The energy efficiency of thermal oxidation systems can be increased, and operating costs correspondingly decreased, by employing heat recovery. Two generic forms of heat recovery can be used, recuperative and regenerative (see below).

Destruction of MC by thermal oxidation results in the formation of HCl; for each pound of MC destroyed, 0.86 lb of HCl is produced. Therefore, thermal oxidation systems for MC destruction will have to incorporate an HCl control process, such as a wet scrubber, and employ special HCl-resistant materials of construction.

The following subsections describe thermal and catalytic oxidation options in more detail. The cost estimates presented include the cost of an HCl scrubber.

a. Recuperative Thermal Oxidizers

A recuperative thermal oxidizer uses a gas–gas heat exchanger, usually of a shell-and-tube design, to preheat the inlet VOC-contaminated air stream using the hot, treated VOC-free gas stream. In some cases, the inlet VOC stream can suffice as the primary fuel for the oxidizer. However, at low VOC concentrations or in cases where the contaminant has a low



1. VOC laden air enters the RVRS system. (flowing upward), and is evenly dispersed by a specially designed screen.
2. VOCs are adsorbed by the polymeric adsorption media, which is flowing downward through the multiple trays inside the adsorption chamber.
3. Clean, treated air is discharged.
4. Saturated media is transferred from bottom tray into hopper, which feeds the regeneration system.
5. Nitrogen blanket covers VOC saturated media in regeneration system.
6. Patented Microwave power generator provides controlled, even heat.
7. Polymeric adsorption media is regenerated.
8. VOC vapors are removed from regeneration system by vacuum, and transferred to the condensers and refrigeration system, where they are cooled and condensed into a liquid.
9. Recovered product is reclaimed and recycled.
10. Regenerated media is transferred from regeneration system, back into the top tray of the adsorption chamber, completing the cycle.
11. Entire process is automated, controlled by PLC electrical control panel.

Figure 6. Fenix MAG 10000™ System. (System is shown for illustrative purposes only, and not as an endorsement of a specific vendor.)

calorific value, auxiliary fuel is required. Recuperative thermal oxidizers can achieve about 80-percent thermal efficiency. Very high organic destruction efficiencies (>99 percent) are typically achieved.

There are a number of vendors of commercial recuperative thermal oxidation systems. The list of suppliers of such systems includes Durr Industries, Reeco, Vara International, and Smith Engineering. Recuperative heat recovery systems are generally not cost effective compared to regenerative systems for process gas flowrates above 50,000 cfm (2). In fact, according to the report (2) supplying the data summarized in Table 21, there were no recuperative thermal oxidizers treating low-concentration, high-flowrate gas streams in the United States in 1995. Capital costs for recuperative systems are about \$40 to \$50/cfm for treating flowrates in the 50,000-cfm range. Annual operating costs are about \$10/cfm.

b. Regenerative Thermal Oxidizers

Regenerative thermal oxidizers, commonly known as RTOs, are much more widely used to treat low-concentration, high-flowrate air streams, as indicated in Table 21. In an RTO (a typical example of which is shown in Figure 7), the contaminated air passes through a heated, ceramic packed bed that preheats the gas to nearly its oxidation temperature. The preheated gas then enters a combustion chamber where it is further heated, if necessary using auxiliary fuel, to the oxidative destruction temperature of the organic contaminants. The hot, clean flue gas then passes through another bed, which has been cooled in a previous cycle, transferring heat to the bed and becoming cooled, in turn. The process is cycled between the beds. That is, when the bed heating the inlet gas cools to a preset temperature, and the bed cooling the discharge gas heats to a corresponding preset temperature, gas flows are switched so inlet gas is directed to the bed formerly handling discharge gas, and vice versa. Auxiliary fuel is used to maintain the interbed combustion chamber temperature. Up to 95-percent heat recovery can be achieved in RTOs. Destruction efficiencies are typically between 97 and 99 percent, levels typically lower than in recuperative thermal oxidizers.

A number of vendors offer RTOs for VOC control. Thermatrix, Inc., markets a flameless RTO that has been shown to effectively treat MC emissions from an herbicide plant. This system was designed to handle a relatively low flowrate of 1,500 scfm, although Thermatrix claims that the system is capable of handling up to 3,000 scfm, and can achieve destruction efficiencies of greater than 99 percent.

Figures 7 and 8 are schematics for two commercially available RTO systems. Capital and annual operating costs for RTO systems are about \$40/cfm and \$8/cfm, respectively,

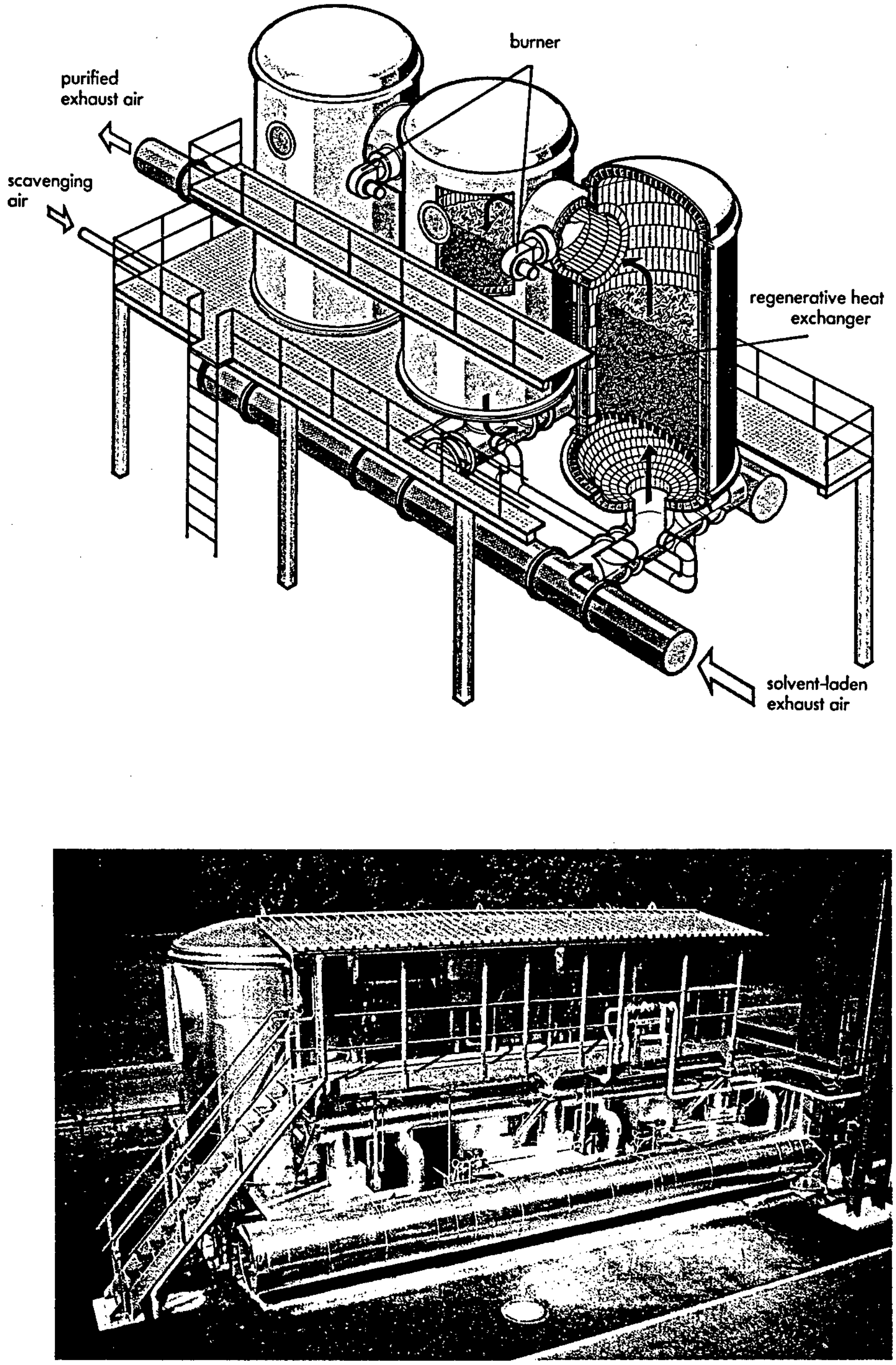
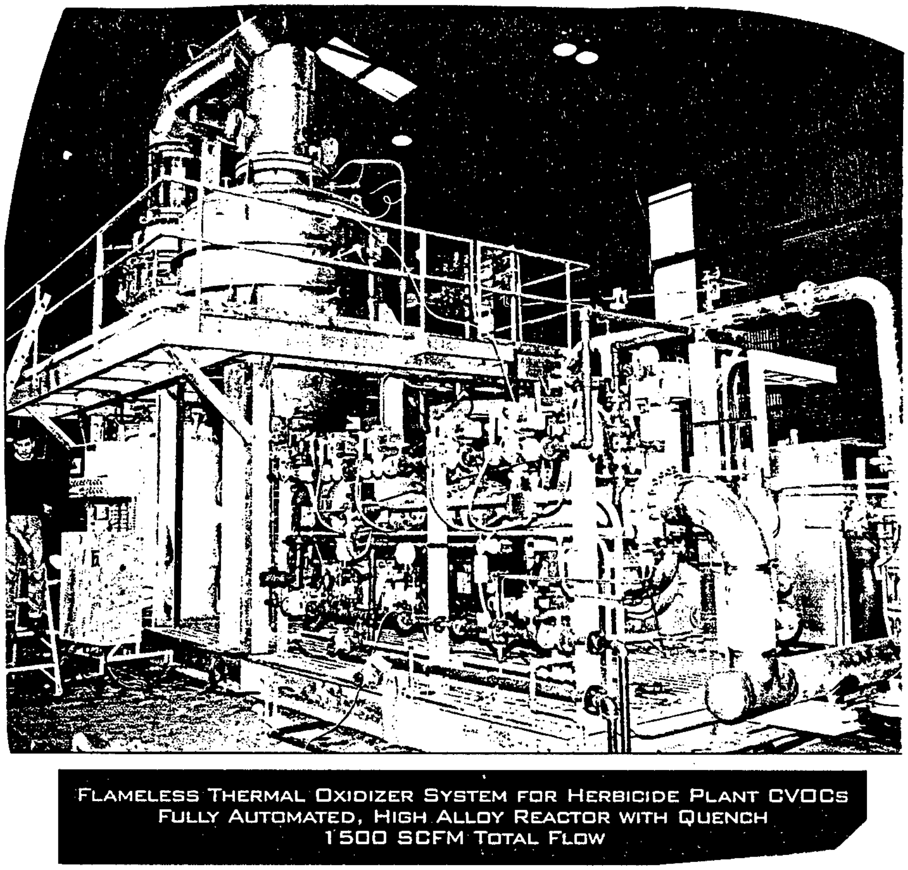


Figure 7. Typical Regenerative Thermal Oxidizer. (System is shown for illustrative purposes only, and not as an endorsement of a specific vendor.)



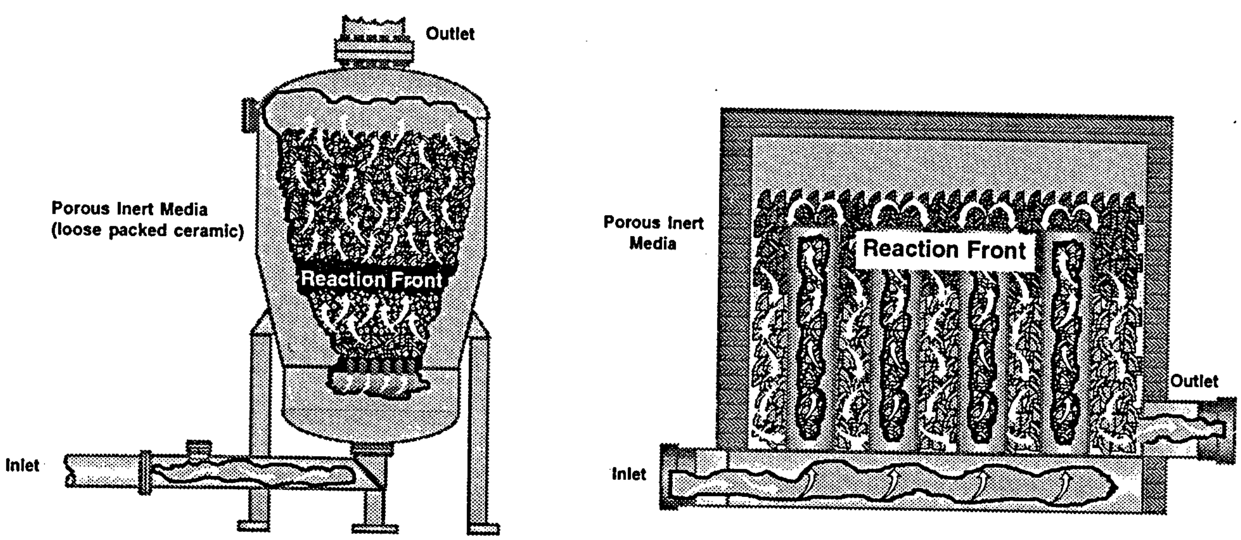


Figure 8. Thermatrix Regenerative Thermal Oxidizer. (System is shown for illustrative purposes only, and not as an endorsement of a specific vendor.)

for inlet gas flowrates of about 50,000 cfm; for flowrates in the 450,000-cfm range, the costs decrease to about $25/cfm and $6/cfm, respectively.

c. Catalytic Oxidizers

Catalytic oxidizers use noble-metal or metal-oxide catalysts to achieve destruction of organics at lower temperatures, between 650° and 950°F. Until recently, catalytic oxidation processes were limited in application to non-chlorinated organic-contaminated gas streams. Thus, for treating large-volume-flowrate gas streams containing MC, this technology must still be considered as emerging, and so is unsuitable for AF depainting facility applications at this time.

3. UV/Ozone Oxidation

Ultraviolet (UV) energy can be used to produce ozone from oxygen, and to excite hydrocarbon molecules to higher activation states so that they will rapidly react with an oxidizing agent, specifically ozone, at ambient temperatures. This process was originally developed to treat organics-contaminated water streams, either process wastewater or contaminated groundwater. In these applications, the process has proven quite effective, ostensibly because it is possible to focus sufficient light energy into a contaminated aqueous stream to effect significant organic compound excitation. Over the past 7 to 8 years, the process has been further developed to treat VOC-contaminated air steams, and several systems have been installed to treat paint booth exhaust.

Two suppliers of this technology were contacted for information: Terr-Aqua Enviro Systems and VM Technologies, Inc. Terr-Aqua Enviro Systems responded with printed information including equipment schematics, case histories and system costs. Figure 9 is a schematic of a typical Terr-Aqua Enviro Systems offering.

As the figure shows, the system relies on two chambers designed to oxidize organic contaminants in the vapor phase, the pre-oxidizer and the photolytic reactor in the figure, as well as a chamber to oxidize contaminants collected in an aqueous phase, the aqua reactor shown in the figure. The mist air dispersion unit shown acts as a wet scrubber designed to scrub organic contaminants not destroyed in the preoxidizer out of the gas and collect them in an aqueous medium for treatment in the aqua reactor. All three reactors noted, the pre-oxidizer, the photolytic reactor, and the aqua reactor, are photolytic reactors fitted with the requisite UV lamps upon which the process relies. Ozone is added to the water that is recirculated through the aqua reactor to supply oxidant to this reactor as well as to the photolytic reactor downstream.

The combination of the pre-oxidizer, mist air dispersion unit, aqua reactor, and photolytic reactor comprise the essential elements of the UV/ozone process. Downstream of this

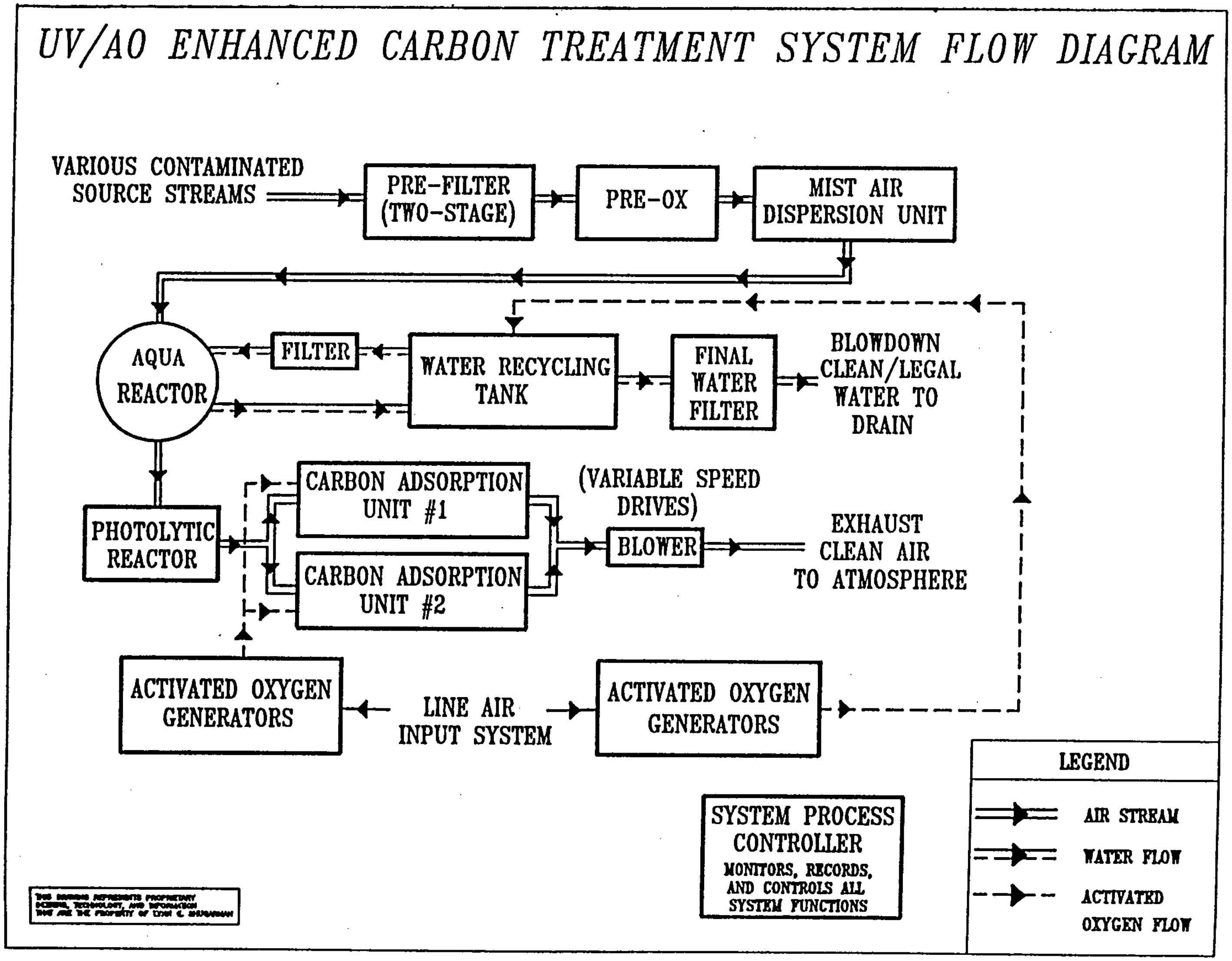


Figure 9. UV/Ozone Oxidation System Schematic — Terr Aqua Enviro Systems UV/AO Enhanced Carbon Treatment System. (System is shown for illustrative purposes only, and not as an endorsement of a specific vendor.)

process are some carbon adsorption units, as shown in Figure 9. These serve to remove any remaining gas stream organic contaminants escaping the UV/ozone process before the gas discharge exhausts to the atmosphere.

At present, there are no publicly available data from full-scale installations on the effectiveness of the UV/ozone process itself in destroying VOC contaminants in gas discharges. All of the publicly available full-scale performance data describe the effectiveness of the entire gas-treatment train, including the carbon adsorbers. Thus, from the available data, it is not possible to evaluate the effectiveness of the UV/ozone process in destroying the gas-stream VOC contaminants, or the relative contributions of the UV/ozone process compared to the carbon adsorbers in removing the VOC contaminants. However, several observations deserve some discussion.

The general experience from past work on the UV/ozone process has been that, while good destruction efficiencies have been measured in organic-contaminated aqueous liquids, the technique has not been particularly effective for destroying VOCs in the vapor phase. This is thought to be due to the inability to concentrate enough light (*i.e.*, to create a high enough photon flux density) in gas-phase streams to be effective in exciting the VOC contaminants. At best, destruction efficiencies in gas-phase streams have been around 30 percent, and these only for photolytically active compounds such as trichloroethylene. Thus, achieving good destruction efficiencies seems to require collecting the contaminant in an aqueous stream, and using UV/ozone to destroy the contaminant in the liquid.

Accordingly, it might be expected that a UV/ozone process, such as that shown in Figure 9, would be effective in treating gas stream VOCs that are water-soluble, such as alcohols and ketones. Water-soluble VOCs would be amenable to collection in the wet scrubber (the mist air dispersion unit); collected aqueous VOCs would be destroyed in the aqua reactor. However, it might also be expected that the process would be only marginally effective in treating VOC contaminants that are insoluble or only sparingly soluble in water, such as MC. The collection efficiency of the mist air dispersion unit will be relatively low for insoluble VOCs; thus, the aqua reactor sees only a fraction of the gas-stream inlet VOCs. Given the limited solubility in water and the expected poor destruction in the two vapor-phase reactors, overall destruction efficiencies by the UV/ozone process are unlikely to exceed 70 to 80 percent. In such instances, the carbon-bed adsorber is presumably not a polishing device, but an essential process operation, performing a significant fraction of the VOC destruction and removal. How significant this fraction is cannot be stated, however, due to the absence of system performance data as noted above.

Information from Terr-Aqua Enviro Systems indicates that capital and annual operating costs for a 10,000-cfm system such as that shown in Figure 9 would each be about $45/cfm. For flowrates greater than 10,000 cfm, a modular approach would be recommended. The capital cost for a 450,000-cfm system is expected to fall to about $25/cfm, with the annual operating cost decreasing to about $5/cfm. However, the operating cost estimates may be somewhat uncertain. These costs will be influenced by the frequency of needed carbon bed regeneration. This frequency will depend heavily on the fraction of VOC-contaminant destruction and removal the adsorbers must perform. As noted above, for treatment of MC-contaminated air streams, this fraction may be significant.

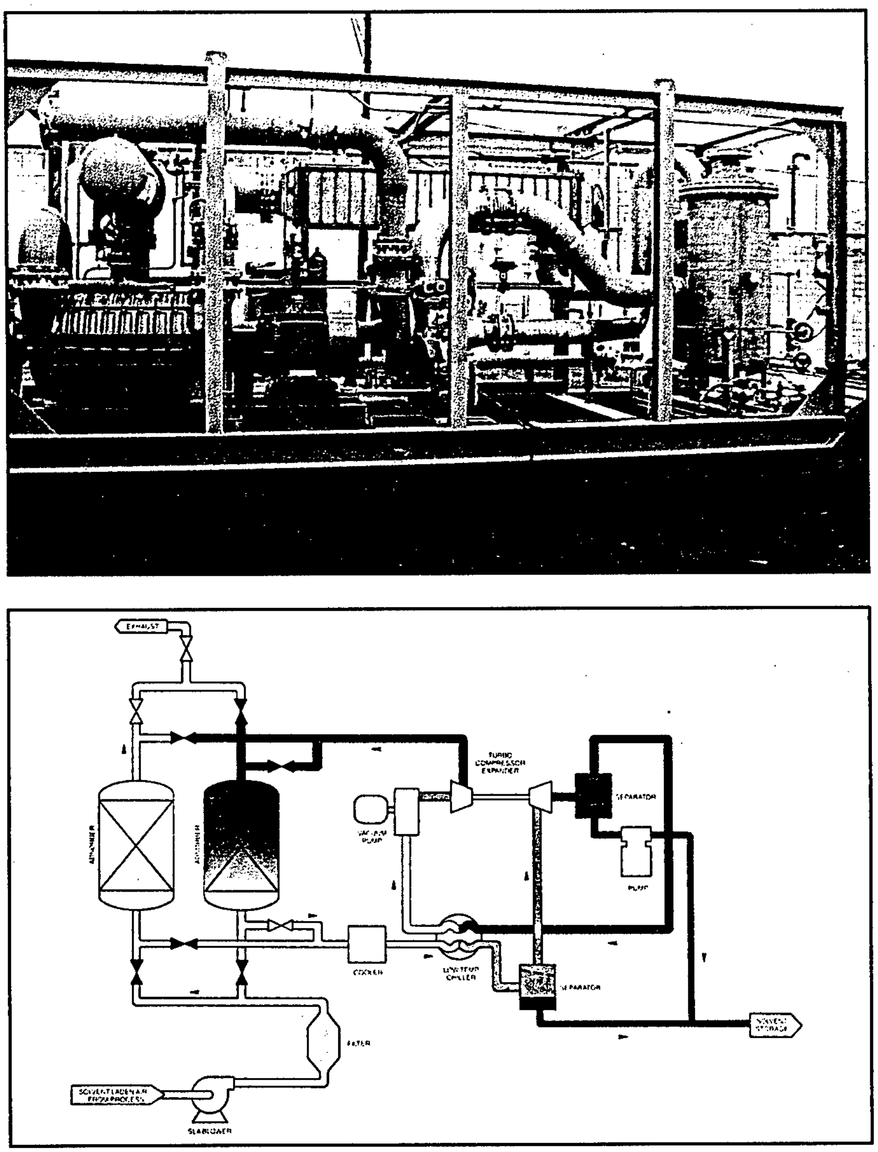
4. MC Recovery Systems

Recovery of VOCs from the exhaust air streams becomes a practical option when the recovered product has reasonable economic value and is present in the air stream at high concentrations. Recovery of VOCs in general and MC in particular can be achieved via: compression condensation (*e.g.*, the reverse-Brayton-Cycle system marketed by NUCON Technologies [see Figure 10]); condensation with mechanical refrigeration; liquid absorption; and cryogenic recovery. Table 23 summarizes the capital and operating costs for these four types of systems.

The reverse-Brayton cycle would be the preferred system over mechanical refrigeration when recovery is an option. The reverse-Brayton cycle can achieve greater recovery efficiencies (*i.e.*, >95 percent) than mechanical refrigeration for units similar in size. Liquid absorption and cryogenic recovery are clearly cost-prohibitive in this case. However, recovery of MC from low-concentration, high-flowrate streams such as those from a depainting facility is not economically feasible unless some cost credit for waste minimization can be realized.

C. TREATMENT TECHNOLOGIES FOR METHYLENE CHLORIDE IN WASTEWATER

As noted in Section IV.A, as much as 52 percent of the MC used for aircraft depainting may accumulate in the wastewater discharge from a facility. This can amount to 160 lb/hr of MC from a facility such as Building 2122 at OC-ALC. An effective method for removing the MC from the wastewater would be air stripping. The MC removed in this manner could then be treated in the exhaust-air-treatment system. Commercial air strippers are available through a number of manufacturers. The capital and annual operating costs of an air-stripping system that uses about 10,000 cfm of stripping air are about $15/cfm and $2/cfm, respectively. If a thermal-oxidation system is used to treat the exhaust air, a portion of the cleaned hot exhaust gas could be used as the carrier gas in the air stripper, making it more efficient and decreasing operating costs.



A skid-mounted, Brayton-cycle heat pump ready for shipment. In the top photo, the vacuum pump (left) and compressor-expander (center) and solvent separator (right) are in the foreground. The diagram at bottom highlights the flow path as the BCHP compresses, cools and expands a solvent-laden gas to condense and separate the solvent.

Figure 10. Brayton Cycle Compression-Condensation Solvent-Recovery System. (System is shown for illustrative purposes only, and not as an endorsement of a specific vendor.)

TABLE 23. CAPITAL AND OPERATING COSTS FOR FOUR VOC/MC-RECOVERY SYSTEMS.

Recovery System	Flowrate (cfm)	Capital Cost ($/cfm)	Annual Operating Cost ($/cfm)
Compression condensation (reverse-Brayton cycle)	50,000	44	20
Mechanical refrigeration	10,000	10	10
Liquid absorption	2,500	>1,000	>500
Cryogenic recovery	500	500	>1,000

Supercritical water oxidation (SCWO), also termed hydrothermal oxidation (HTO), is an emerging technology that is being investigated (6) at the laboratory scale for MC destruction.[3] Water above its critical point (371°C and 221 atm) can dissolve almost any organic compound. Under these conditions, MC oxidation by air or oxygen added to the water is quite rapid. Reaction products are the same as with thermal oxidation, HCl and CO_2, but combustion by-products are avoided. There has been some interest within the AF in SCWO for eventual use in wastewater-treatment applications. However, this technology is not yet ready for large-scale application or commercialization.

D. INTEGRATED APPROACHES TO METHYLENE-CHLORIDE CONTROL FOR APPLICATION TO LARGE-AIRCRAFT-DEPAINTING HANGARS

As noted above, the cost of an emission-control system is proportional to the flowrate of the gas stream controlled. Therefore, in any VOC-emission-control strategy, any means of reducing the flowrate of the inlet stream to the treatment device results in lower treatment-device capital and operating costs. Figure 11 illustrates a number of generic MC-control strategies incorporating flow reduction.

Internal flow-reduction measures (*i.e.*, flow reduction through manipulation of facility-ventilation systems; see Section V), if applicable, can realistically achieve, at most, a 50-percent reduction in the exhaust volumetric flowrate before VOC concentrations in the recirculated gas reach levels considered unacceptable for worker health, safety, or comfort reasons. External flow

[3] Communications with Dr. J. Wander, USAF AL/EQ, January 1997, Tel.: (904) 283-6240.

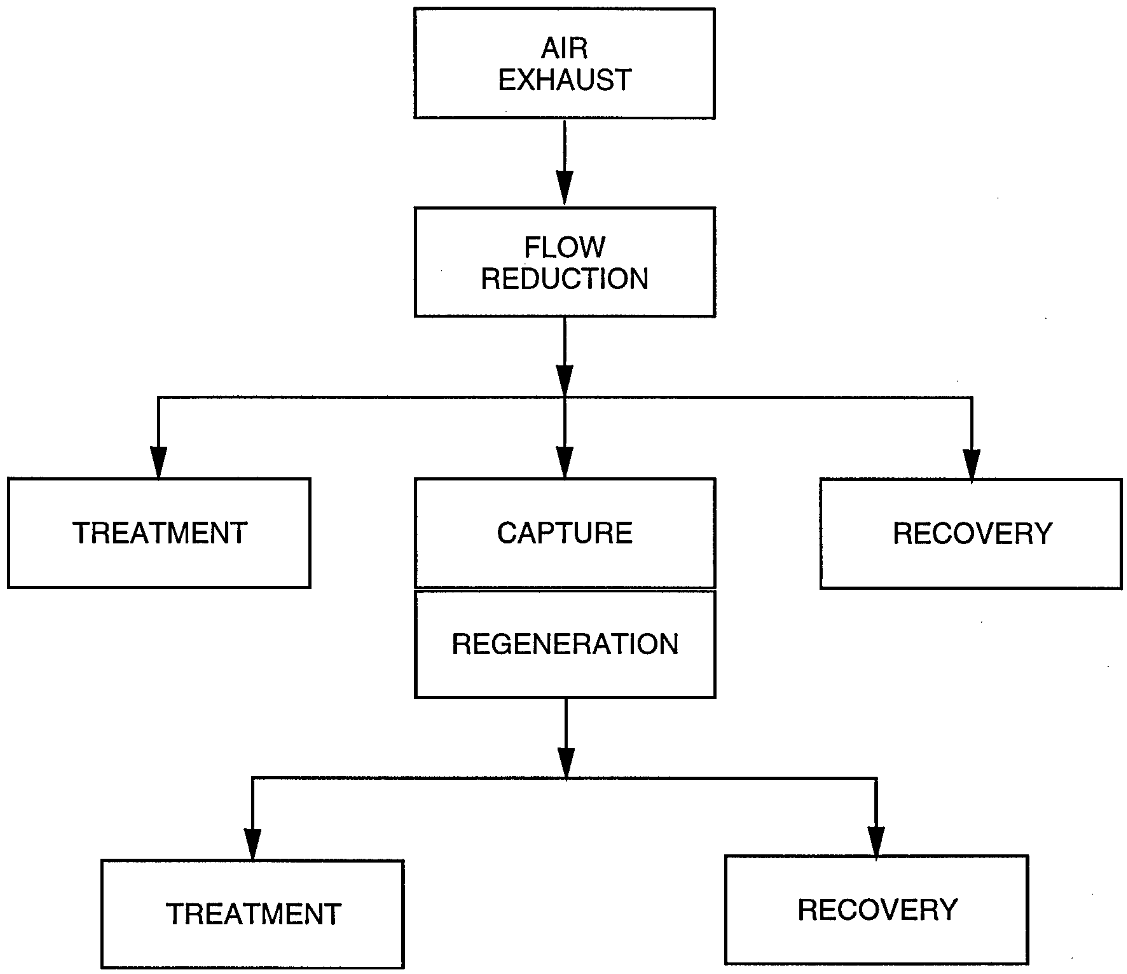
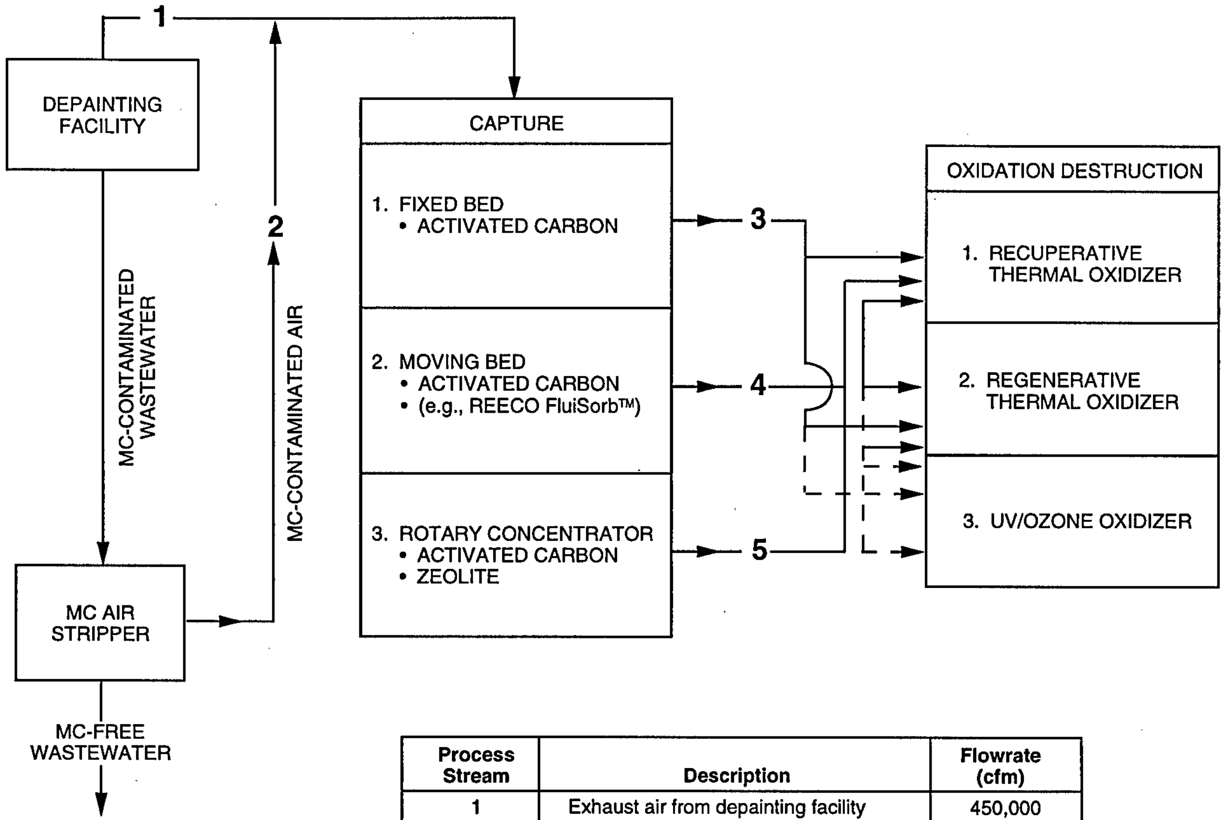


Figure 11. Generic MC-Control Strategies.

reduction, *i.e.*, flow reduction after the exhaust air leaves the facility, can be achieved by any one of the various adsorption techniques discussed in Section IV.B. For example, the discussion in Section IV.B noted that conventional carbon-adsorption beds can achieve 40-fold flow reduction ratios, while rotary concentrators can achieve 10-fold flow reductions.

Figure 12 is a flow diagram showing various possible combinations of MC-capture and subsequent treatment options. The choice of the most effective and most cost-effective option for use in a given application is highly application- and location-specific. All options shown in Figure 12 follow the general strategy of flow reduction by adsorption, with subsequent desorption, and then treatment by oxidation. The five numbered process streams shown in Figure 12 are Process Stream 1 (450,000 cfm), the MC-contaminated stream exiting the depainting facility (*e.g.*, one of the bays of Building 2122 at OC-ALC); Process Stream 2 (5,000 cfm), the MC-



Process Stream	Description	Flowrate (cfm)
1	Exhaust air from depainting facility	450,000
2	MC-contaminated air from air stripper	5,000
3	Exit air from fixed-bed carbon adsorber	12,000
4	Exit air from "FluiSorb" system	50
5	Exit air from rotary concentrator	45,500

Figure 12. Possible MC-Control Approaches Incorporating External Flow Reduction Followed by Destruction Via Oxidation.

contaminated stream from a wastewater MC air stripper; Process Stream 3 (12,000 cfm), the MC-contaminated stream exiting a fixed-bed carbon-adsorption system upon regeneration (based on a 40-fold flow reduction); Process Stream 4 (50 cfm), the MC-contaminated stream exiting a FluiSorb™ system (based on a 10,000-fold flow reduction as claimed by the FluiSorb™ vendor, Reeco); and Process Stream 5 (45,500 cfm), the MC-contaminated stream exiting a rotary concentration device (based on a 10-fold flow reduction). The recommended treatment method for Process Streams 3, 4, and 5 is thermal oxidation. UV/ozone oxidation has the potential for application in all cases, but the technology needs to be further tested to demonstrate that the required destruction efficiency for MC can be achieved and maintained, and that it has the needed overall durability. For this reason, the process stream lines leading to UV/ozone treatment are shown as dashed lines in Figure 12.

Table 24 is a summary of capital-investment and annual operating costs for the various control strategies illustrated in Figure 12. No cost information on the FluiSorb system is given in the table because none was available at the time of this writing. However, this system is included in the table because, if applicable to this situation, the system can potentially reduce downstream treatment costs significantly, and its use may even allow consideration of MC recovery options.

The information in Table 24 shows that the capital-investment cost of controlling MC from a large-aircraft depainting facility, such as one of the aircraft-depainting bays in Building 2122, will likely be in the range of $5M to $6.5M. The annual operating costs are expected to be in the range of $0.8M to $1.5M. The costs may be decreased somewhat if internal flow-volume-reduction techniques are implemented. However, control costs will be incurred if MC use is continued after September 1998. The cost tradeoffs associated with controlling MC compared to the use of alternative depainting methods are discussed in Section VI.

TABLE 24. COST-ANALYSIS SUMMARY OF MOST-LIKELY TECHNOLOGIES.

Technology	Fixed-Bed (Carbon)	Moving-Bed (FluiSorb™)	Rotary Concentration (Carbon, Zeolite)
Capture Technology			
Inlet flowrate (cfm)	455,000	455,000	455,000
CI[a] ($/cfm)	10	N.A.[b]	10
AOC[c] ($/cfm)	1.6	N.A.	1.6
1. CI ($)	4,550,000	—	4,550,000
2. AOC ($)	728,000	—	728,000
Thermal Oxidation Systems			
Inlet flowrate (cfm)	12,000	50	45,500
CI ($/cfm)	40	—	40
AOC ($/cfm)	8	—	8
3. CI ($)	480,000	200,000	1,820,000
4. AOC ($)	96,000	40,000	364,000
UV/Ozone Oxidation Systems			
Inlet flowrate (cfm)	12,000	50	45,500
CI ($/cfm)	45	—	45
AOC ($/cfm)	15	—	15
5. CI ($)	540,000	225,000	2,047,500
6. AOC ($)	180,000	75,000	682,500
Air Stripping System			
Inlet flowrate (cfm)	5,000	5,000	5,000
CI ($/cfm)	10	10	10
AOC ($/cfm)	2	2	2
7. CI ($)	50,000	50,000	50,000
8. AOC ($)	10,000	10,000	10,000
Totals			
Thermal Oxidation			
CI (1+3+7) ($)	5,080,000	N.A.	6,420,000
AOC (2+4+8) ($)	834,000		1,102,000
UV/Ozone Oxidation			
CI (1+5+7) ($)	5,140,000	N.A.	6,647,500
AOC (2+6+8) ($)	918,000		1,426,000

[a]CI = Capital investment.
[b]N.A. = Not available.
[c]AOC = Annual operating cost.

E. LIST OF MC CONTROL DEVICE VENDORS

Alzeta Corporation
2343 Calle Del Mundo
Santa Clara, CA 95054-1008
Tel.: (408) 727-8282
POC: J. A. Gotterba

Durr Industries
Environmental Systems Division
40600 Plymouth Road, P.O. Box 2129
Plymouth, MI 48170-4297
Tel.: (313) 459-6800
POC: Mark Hill, (415) 669-1111

Fenix Systems, Ltd.
31500 W. 13 Mile Rd., Suite 220
Farmington Hills, MI 48334
Tel.: (800) 676-0183
POC: Rod Prodonovich

Met-Pro
Systems Division
160 Cassell Road
Harleysville, PA 19438
Tel.: (215) 723-6751
POC: Fred Rowley

Munters Corporation
Zeol Division
Amesbury, MA 01913-0600
Tel.: (508) 388-2666
POC: J. Gronvaldt

NUCON International, Inc.
P.O. Box 29151
7000 Huntley Rd.
Columbus, OH 43229
Tel.: (614) 846-5710
POC: Joseph E. Enneking

Reeco
A Research Cottrel Company
U.S. Highway 22 West and Station Road
Branchburg, NJ 08876
Tel.: (908) 685-4000
POC: Ed Biedell

Terr-Aqua Enviro Systems, Inc.
700 E. Alosta Ave, #19
Glendora, CA 91740
Tel.: (818) 969-7531
POC: Trina E. Jackson

Vara International
Division of Calgon Corporation
1201 19th Place
Vero Beach, FL 32960
Tel.: (561) 567-4108
POC: D. Lobmeyer

F. REFERENCES FOR SECTION IV

1. Design Alterations to Ventilation System. Corrosion Control Facility, Building 2280, Tinker AFB, OK, report prepared for Tulsa District COE, Tulsa, Oklahoma, by Bouillon Christofferson and Schairer, Seattle, Washington, under Contract No. DACA56-93-C-0046, 1993.

2. Survey of Control Technologies for Low Concentration Organic Vapor Gas Streams, EPA-456/R-95-003, May 1995.

3. OAQPS Control Cost Manual, Fourth Ed., EPA 450/3-90-006, with Control Cost Spread Sheets. W. M. Vatavuk. February 1996. http://www.rtpnc.epa.gov.

4. Chemical Engineering, every issue, Mc-Graw-Hill.

5. Ivey, D. C., Optimizing Activated Carbon Adsorption for VOC/HAP Control, paper 95-WA78A.02, presented at the AWMA 88th Annual Meeting and Exhibition, San Antonio, Texas, June 1995.

6. Marrone, P., *et al.*, Oxidation and Hydrolysis of Acetic Acid and Methylene Chloride in Supercritical Water as a Means of Remediation, http://128.6.70.23/html_docs/rrel/marrone.html.

SECTION V

POTENTIAL FLOW-REDUCTION STRATEGIES APPLICABLE TO A LARGE-AIRCRAFT-PAINTING/DEPAINTING FACILITY

This section discusses potential strategies and their limitations for reducing the flowrate of the exhaust air from large-aircraft painting/depainting hangars. The section also discusses the application of these potential strategies to the MC-based depainting facility in Building 2122 at OC-ALC. As described in Section II, aircraft such as KC-135s, C-141s, C-130s, C-5s, B-52s, and E-3s are usually depainted in large hangars. Exhaust-air flowrates from the facilities that use chemical stripping processes can range between 400,000 and 600,000 cfm. Because the cost of controlling emissions in a VOC-contaminated air stream is proportional to the volume flowrate of the stream, anything that is done to effect flow reduction will decrease the cost of the control process.

A. FLOW-REDUCTION STRATEGIES

Reduction in the volume flowrate of exhaust air can be achieved in one, or a combination, of the following ways:

- Simple flow reduction
- Simple recirculation
- Simple split flow
- Split flow with recirculation
- External flow reduction

The first four of the above were termed internal flow reduction in Section IV.D. Each of these is discussed in the following subsections.

1. Simple Flow Reduction

Simple flow reduction can be easily achieved by reducing the overall flowrate through, or the ventilation rate of, the facility. However, this strategy may not be possible if the resulting VOC concentration in the facility increases to levels that raise worker health and safety concerns. For example, the exhaust air flowrate from Building 2122 at Tinker AFB is typically 440,000 cfm. The corresponding average measured MC concentration in the building during depainting is 125 ppm. If that exhaust flow were reduced to 60,000 cfm, it might become possible to identify and install a cost-effective MC emission control system. However, reducing the building exhaust flowrate to 60,000 cfm will cause a corresponding increase in the building's average MC concentration to more than 500 ppm. At this higher workplace MC concentration, PPE

requirements would be increased. At present, Building 2122 workers wear a loose-hood supplied-air respirator that provides a protection factor of 25. At the higher concentration, a protection factor of at least 100 would be required to maintain current exposure levels. The effects of the more protective PPE could include greater worker discomfort, with associated reduced depainting efficiency.

2. Simple Recirculation

In simple recirculation, a fraction of the exhaust stream is returned to the depainting facility and combined with fresh makeup air. The remainder of the exhaust is either discharged or directed to the VOC-control device. Figure 13 illustrates the simple recirculation concept of flow reduction. In addition to the reduction in the exhaust volume needing to be treated, another advantage of recirculation is realized via reductions in heating and air-conditioning costs.

The fraction of the exhaust air that can be returned to the facility is, again, determined by the exhaust-stream VOC concentration. Like simple flow reduction, simple recirculation causes an increase in VOC concentration in the building, which, in turn, will likely dictate more-protective PPE.

3. Simple Split Flow

The concept of split flow takes advantage of any VOC-concentration gradients that may exist within a painting/depainting facility to decrease the flowrate of the exhaust-air stream. Figure 14 illustrates the simple split-flow concept. In instances in which vertical concentration gradients exist in the VOC contaminants, the exhaust air can be split into two streams. One

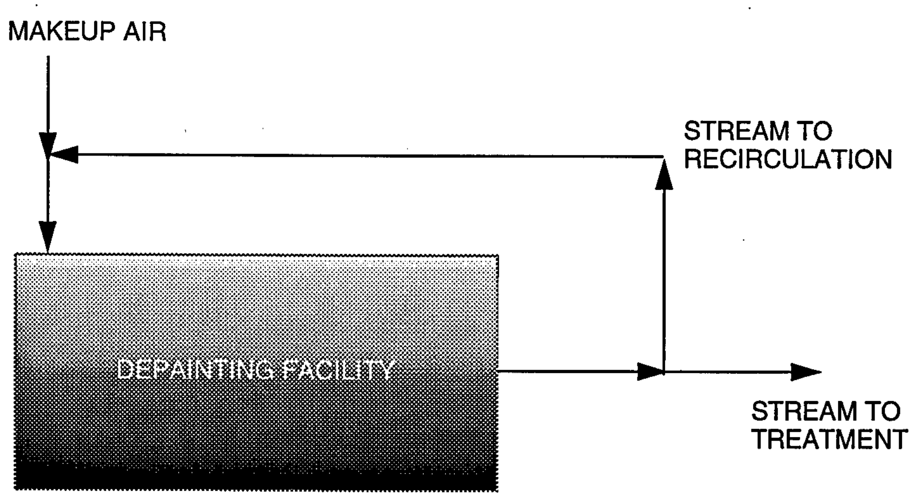


Figure 13. Simple Recirculation.

Figure 14. Simple Split Flow.

stream, typically the lower stream, will contain the contaminants at higher concentrations. The second stream will contain the contaminants at lower concentrations. In favorable situations, it may be possible to design the flow-split proportions so that this second stream's contaminant concentrations are below permissible discharge levels.

Split flow has been shown to be capable of achieving up to 75-percent reduction in exhaust-flow volume from paint booths. Because MC is heavier than air, concentration gradients within a depainting facility may exist to the extent that benefits from split flow can be realized. However, concentration gradients as great as those commonly encountered in a paint-spray booth may not exist in an MC-depainting facility, and it may not be possible to achieve as large a reduction via split flow.

4. Split Flow with Recirculation

The aerospace rework NESHAP may all but eliminate the possibility of venting a split-exhaust air stream to the atmosphere. As a result, a closed-loop approach, in which the low-concentration split is recirculated back into the facility after fresh makeup air has been added, may be indicated. Figure 15 illustrates this concept. In practice, a split-flow design should incorporate the capability of zero recirculation and total-exhaust-air treatment, as well as variable split flow volumes. This flexibility is needed to ensure that the workplace VOC concentrations will not exceed defined exposure limits. As in the case of simple flow reduction and simple recirculation, the need for more-protective PPE will have to be considered. Also, as in the case of simple recirculation, reductions in heating and air-conditioning costs may be realized with split-flow recirculation.

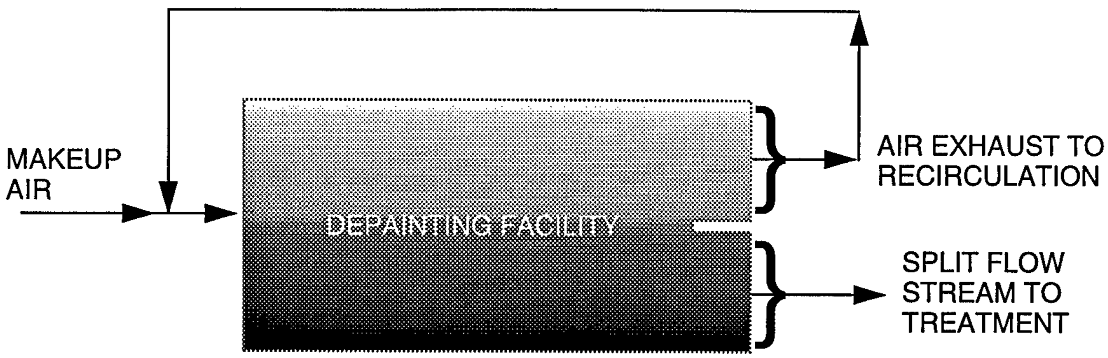


Figure 15. Split Flow with Recirculation.

5. External Flow Reduction

Significant effective reductions in exhaust flow may be achieved by using VOC-capture controls employing activated carbon, polymeric, or zeolitic adsorbers. The devices can use fixed-bed, moving-bed, or rotary concentrators, as discussed in detail in Section IV. The contaminated exhaust stream is passed through the adsorption unit, which captures the MC. The adsorbing medium is then regenerated, yielding a lower-volume flow more concentrated in MC, which is directed to the MC-treatment (control) unit. Because the exhaust air leaving the adsorption device during capture operation will be contaminant-free, it can be recirculated back into the facility. Activated-carbon-based fixed-bed adsorbers are, in effect, capable of concentrating low-concentration, high-flowrate air streams by a factor of 30 to 40, as noted in Section IV.B. Zeolitic rotary concentrators can provide 10-fold volume reductions. Figures 16 and 17 show the concept of flow reduction using adsorbers without and with recirculation, respectively.

B. FLOW-REDUCTION STRATEGIES FOR BUILDING 2122 AT OC-ALC

Building 2122 is the largest MC-based aircraft depainting facility operated by the AF. The building is approximately 150 yd x 65 yd in area and 35 feet in height to the trusses. The building consists of three bays, as shown in Figure 18. Bay I and Bay III are utilized for stripping paint from aircraft frames. Bay II is used mainly for stripping paint from aircraft parts. The three bays are currently not isolated from one another.

1. Existing Ventilation Scheme

Ten exhaust fans, each with a capacity of 110,000 cfm, service Building 2122. There are four exhaust fans each in Bays I and III, and two exhaust fans in Bay II. The exhaust-fan plenum is located about 10 feet above ground level at the north side of the building.

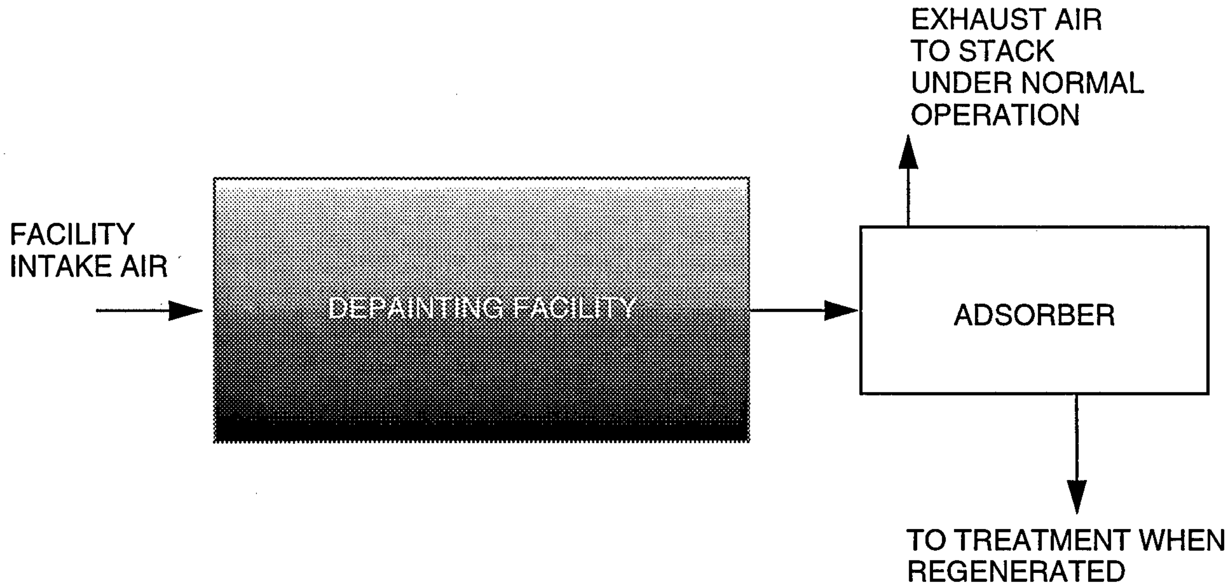


Figure 16. Flow Reduction with VOC Adsorber.

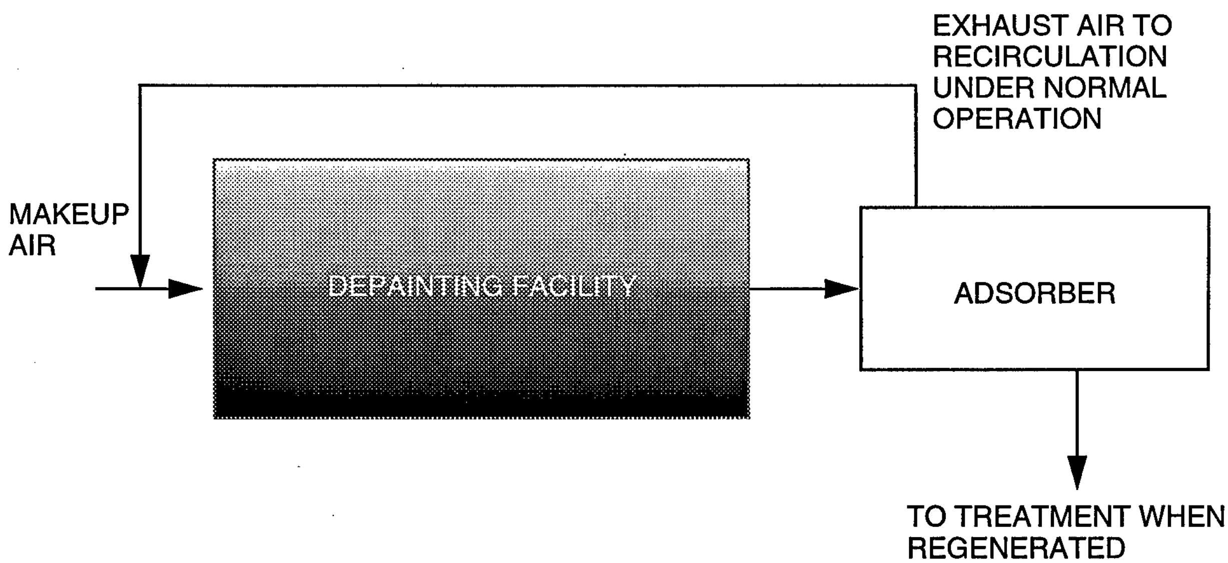


Figure 17. Flow Reduction with Adsorber and Recirculation.

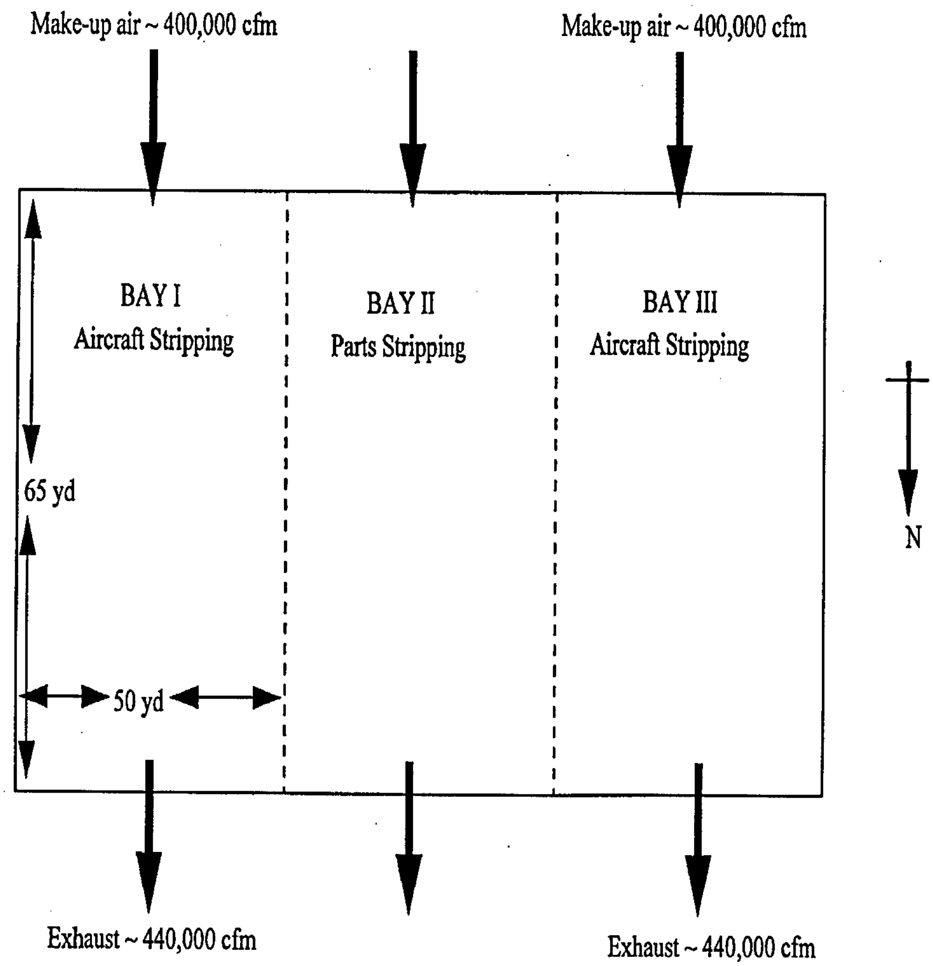
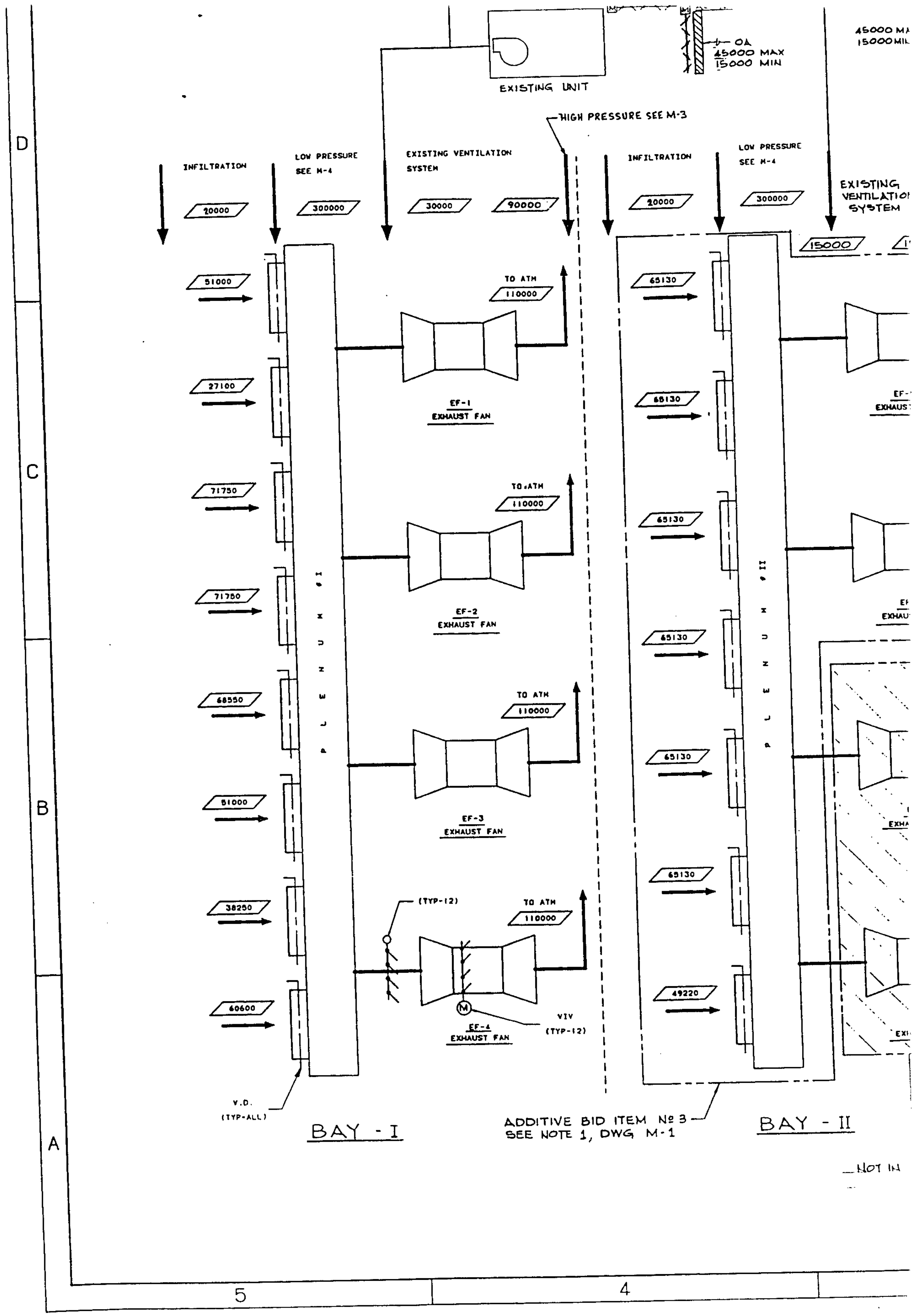


Figure 18. Schematic of Building 2122 at OC-ALC.

Makeup air is provided by two sets of fans. One set consists of 15 low-pressure fans per bay, each with a capacity of 20,000 cfm. These fans are located on the building wall opposite from the exhaust fans, with their makeup-air plenum about 25 feet above the floor. The second set consists of two high-pressure fans per bay, each fan having a capacity of 45,000 cfm. These fans are located on the same side of the building as the exhaust fans, but are ducted to route the air across the bay toward the low-pressure-fan makeup plenum. The high-pressure makeup air is taken from a collection of 20 diffusers in each bay.

The resulting ventilation pattern is cross-flow, with the air moving from the south face of the building to the north face. Figures 19, 20, and 21 are process flow diagrams for the existing ventilation system, provided by the Facilities Engineer at Building 2122.



EXISTING UNIT
OA
45000 MAX
15000 MIN
45000 MA
15000 MIN
HIGH PRESSURE SEE M-3
INFILTRATION
LOW PRESSURE SEE M-4
EXISTING VENTILATION SYSTEM
20000
300000
30000
90000
15000
51000
27100
71750
71750
68550
51000
38250
60600
65130
65130
65130
65130
65130
65130
49220
TO ATM
110000
EF-1 EXHAUST FAN
EF-2 EXHAUST FAN
EF-3 EXHAUST FAN
EF-4 EXHAUST FAN
(TYP-12)
VIV (TYP-12)
V.D. (TYP-ALL)
PLENUM #I
PLENUM #II
BAY - I
BAY - II
ADDITIVE BID ITEM № 3
SEE NOTE 1, DWG M-1
NOT IN
D
C
B
A
5
4

1

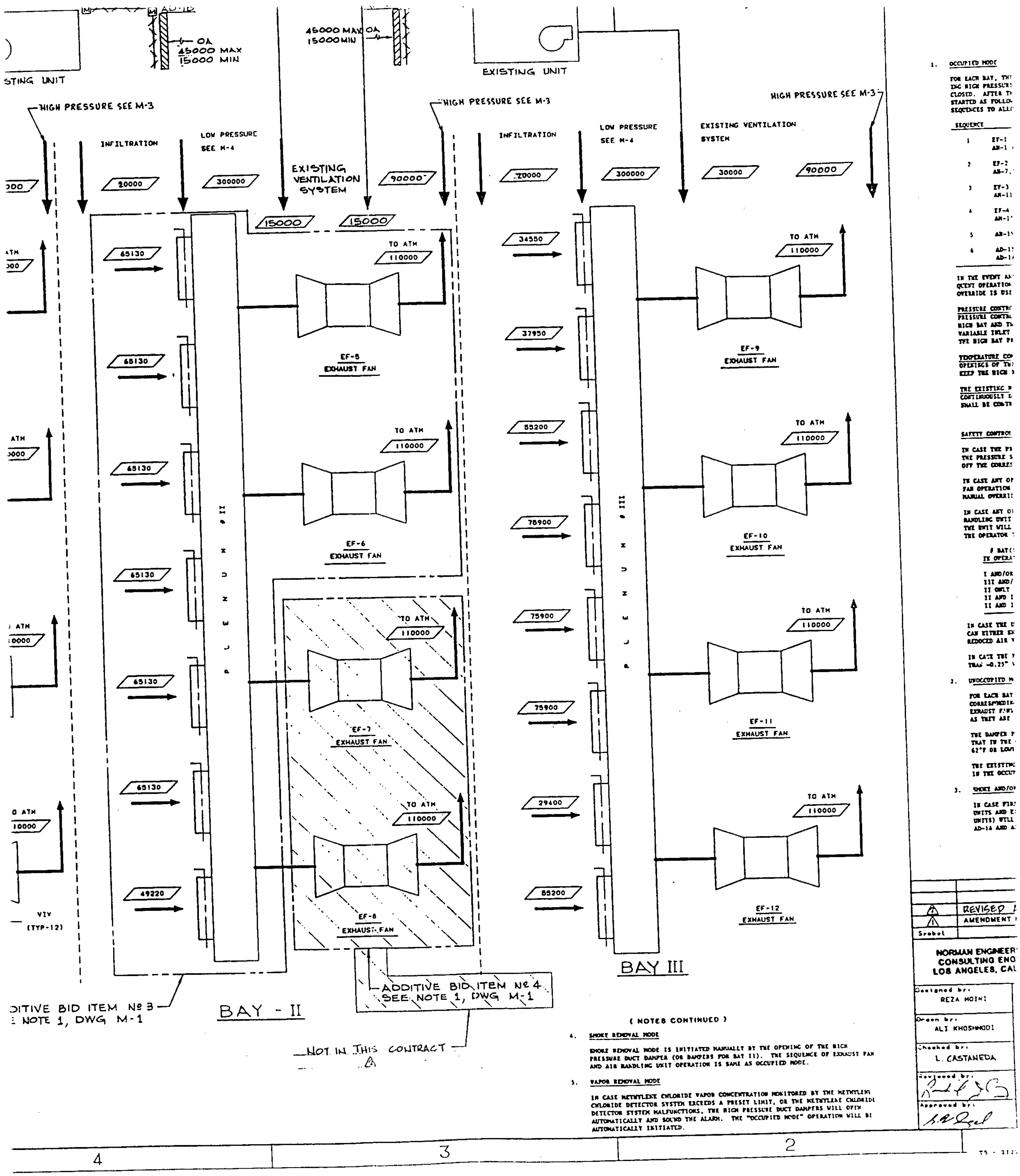
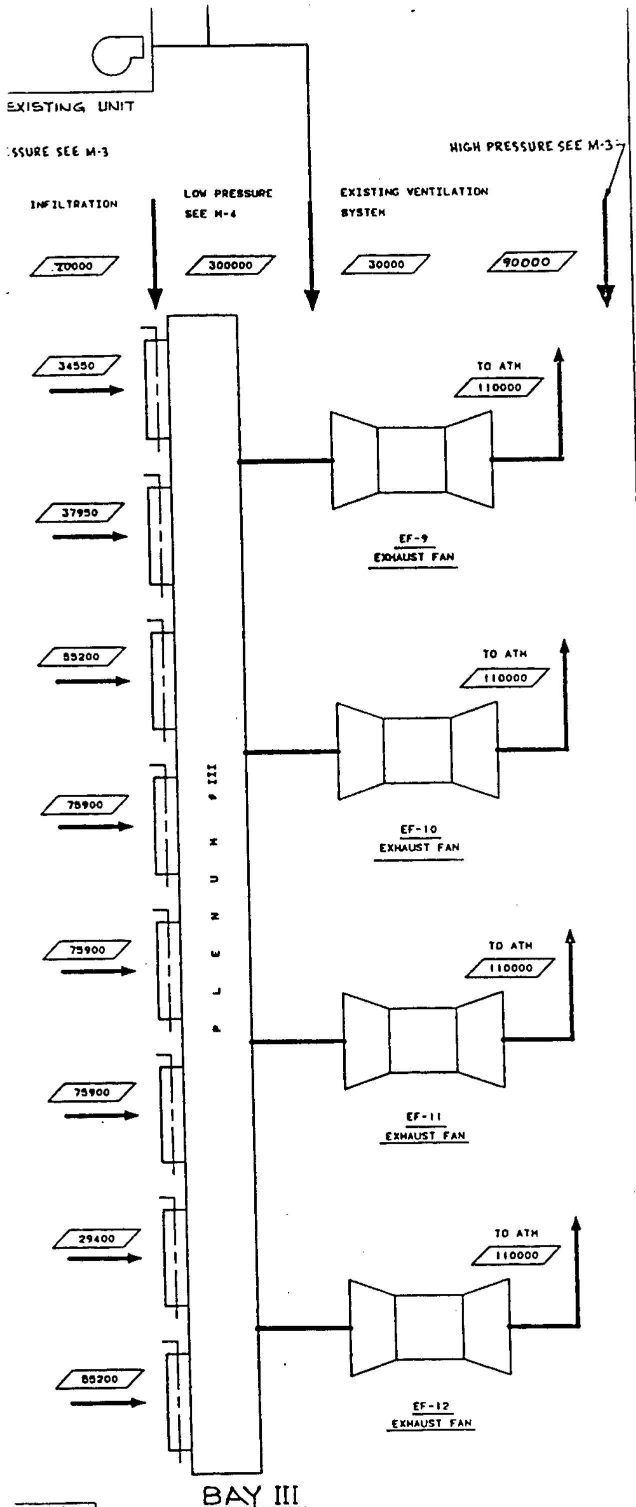


Figure 19. Schematic o
in Building 2

2

3. EXISTING VENTILATION SYSTEM SHALL BE MAINTAINED IN MAINTENANCE MODE



SEQUENCE OF OPERATION

1. OCCUPIED MODE

FOR EACH BAY, THE OCCUPIED MODE IS INITIATED BY OPENING OF THE CORRESPONDING HIGH PRESSURE DUCT DAMPER (OR DAMPERS FOR BAY I) WHICH IS NORMALLY CLOSED. AFTER THE INITIATION, ALL FANS AND AIR HANDLING UNITS WILL BE STARTED AS FOLLOWS: THERE SHOULD BE ONE MINUTE TIME DELAY BETWEEN SEQUENCES TO ALLOW THE FAN MOTORS TO REACH RATED SPEED.

SEQUENCE	BAY I		BAY II		BAY III	
1	EF-1 AH-1 & 2	ON ON	EF-5 AH-3 & 4	ON ON	EF-9 AH-5 & 6	ON
2	EF-2 AH-7,8,9,10	ON ON	EF-6 AH-22,23,24,25	ON ON	EF-10 AH-37,38,39,40	ON ON
3	EF-3 AH-11,12,13,14	ON ON	EF-7 AH-26,27,28,29	ON ON	EF-11 AH-41,42,43,44	ON ON
4	EF-4 AH-15,16,17,18	ON ON	EF-8 AH-30,31,32,33	ON	EF-12 AH-45,46,47,48	ON ON
5	AH-19,20,21	ON	AH-34,35,36		AH-49,50,51	ON
6	AD-1B AD-1A	OPEN CLOSE	-		AD-2A AD-2B	OPEN CLOSE

IN THE EVENT ANY COMPONENT (EXCEPT AH-7 THRU 51) FAILS, THE ENTIRE SUBSEQUENT OPERATIONS SHALL BE STOPPED UNTIL THE FAILURE IS CORRECTED OR MANUAL OVERRIDE IS USED.

PRESSURE CONTROL: THE PRESSURE OF EACH HIGH BAY IS CONTROLLED BY A PRESSURE CONTROLLER WHICH SENSES THE PRESSURE DIFFERENTIAL BETWEEN THE HIGH BAY AND THE ATMOSPHERE. THE PRESSURE CONTROLLER THEN VARIES THE VARIABLE INLET VANES OF THE EXHAUST FANS (FOUR FOR EACH BAY) TO MAINTAIN THE HIGH BAY PRESSURE AT -0.05" WC.

TEMPERATURE CONTROL: A THERMOSTAT LOCATED IN EACH BAY WILL MODULATE THE OPENINGS OF THE VALVES OF THE STEAM COILS IN ALL THE AIR HANDLING UNITS TO KEEP THE HIGH BAY TEMPERATURE AT 60°F IN THE WINTER.

THE EXISTING HOUSE HEATING AND VENTILATING SYSTEM: THE SYSTEM WILL WORK CONTINUOUSLY DURING THIS MODE. THE STEAM VALVES FOR THE HEATING COILS SHALL BE CONTROLLED TO MAINTAIN THE HIGH BAY AT 60°F IN WINTER (EXISTING).

SAFETY CONTROLS:

IN CASE THE PRESSURE IN THE HIGH PRESSURE PLENUM EXCEEDS THE PRESET POINT, THE PRESSURE SWITCH LOCATED AT THE PLENUM WILL INITIATE ALARMS AND TURN OFF THE CORRESPONDING AIR HANDLING UNITS.

IN CASE ANY OF THE EXHAUST FANS FAIL TO TURN ON, THE SEQUENCE OF UNIT AND FAN OPERATION SHOWN ABOVE WILL STOP AND AN ALARM WILL BE INITIATED. MANUAL OVERRIDE IS PROVIDED.

IN CASE ANY OF THE FLOW SWITCHES AT THE OUTLET OF THE HIGH PRESSURE AIR HANDLING UNIT EXPERIENCES A LOW FLOW WHEN THE CORRESPONDING UNIT IS ON, THE UNIT WILL BE TURNED OFF ELECTRICALLY AFTER A TIME DELAY AND SET ALARM. THE OPERATOR THEN HAS THE FOLLOWING OPTIONS:

# BAY(S) IN OPERATION	UNIT # FAILS	UNIT TO BE TURNED ON MANUALLY
I AND/OR II	AH-1 OR 2	AH-3
III AND/OR I	AH-5 OR 6	AH-4
II ONLY	AH-3 OR 4	AH-1,2,5 OR 6
II AND I	AH-3 OR 4	AH-5 OR 6
II AND III	AH-3 OR 4	AH-1 OR 2

IN CASE THE UNIT REQUIRED TO BE TURNED ON IS NOT AVAILABLE, THE OPERATOR CAN EITHER SHUT DOWN THE OPERATION OF THE BAY OR OPERATE THE BAY WITH REDUCED AIR VELOCITY.

IN CASE THE PRESSURE IN THE BAYS WITH RESPECT TO THE ATMOSPHERE IS HIGHER THAN -0.25" WC OR LOWER THAN -0.30" WC, ALARM WILL BE SET OFF.

2. UNOCCUPIED MODE

FOR EACH BAY THE UNOCCUPIED MODE IS INITIATED BY CLOSING OF THE CORRESPONDING HIGH PRESSURE DUCT DAMPER (OR DAMPERS FOR BAY II). THE EXHAUST FANS AND AIR HANDLING UNITS ARE TURNED OFF IN THE SAME SEQUENCE AS THEY ARE TURNED ON IN THE OCCUPIED MODE.

THE DAMPER POSITIONS OF AD-1 A & B AND AD-2 A & B WILL REMAIN THE SAME AS THAT IN THE OCCUPIED MODE EXCEPT WHEN THE HIGH BAY TEMPERATURE DROPS TO 62°F OR LOWER. AT THIS CONDITION, THE DAMPER POSITIONS WILL BE REVERSED.

THE EXISTING HEATING AND VENTILATING SYSTEM WILL OPERATE CONTINUOUSLY AS IN THE OCCUPIED MODE.

3. SMOKE AND/OR FIRE MODE

IN CASE FIRE AND/OR SMOKE DETECTORS ACTIVATE IN ANY MODE, ALL AIR HANDLING UNITS AND EXHAUST FANS (INCLUDING THE EXISTING HEATING AND VENTILATING UNITS) WILL BE SHUT DOWN. ALL HIGH PRESSURE DUCT DAMPERS WILL BE CLOSED. AD-1A AND AD-2B WILL ALSO BE CLOSED.

M NO 4, M-1

(NOTES CONTINUED)

4. SMOKE REMOVAL MODE

SMOKE REMOVAL MODE IS INITIATED MANUALLY BY THE OPENING OF THE HIGH PRESSURE DUCT DAMPER (OR DAMPERS FOR BAY II). THE SEQUENCE OF EXHAUST FAN AND AIR HANDLING UNIT OPERATION IS SAME AS OCCUPIED MODE.

5. VAPOR REMOVAL MODE

IN CASE METHYLENE CHLORIDE VAPOR CONCENTRATION MONITORED BY THE METHYLENE CHLORIDE DETECTOR SYSTEM EXCEEDS A PRESET LIMIT, OR THE METHYLENE CHLORIDE DETECTOR SYSTEM MALFUNCTIONS, THE HIGH PRESSURE DUCT DAMPERS WILL OPEN AUTOMATICALLY AND SOUND THE ALARM. THE "OCCUPIED MODE" OPERATION WILL BE AUTOMATICALLY INITIATED.

Symbol	Revisions	Date	Approved
2	REVISED AS BUILT	7-21-88	
1	AMENDMENT NO. 0001	9 SEP 86	

NORMAN ENGINEERING CO.
CONSULTING ENGINEERS
LOS ANGELES, CALIFORNIA

U.S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
TULSA, OKLAHOMA

PN 11196 FY 86

TINKER AIR FORCE BASE
OKLAHOMA CITY, OKLAHOMA
ALTER AIRCRAFT CORROSION FACILITY

HVAC PROCESS FLOW
EXHAUST SYSTEM

Designed by: REZA MOINI
Drawn by: ALI KHOSHNOODI
Checked by: L. CASTANEDA
Reviewed by:
Approved by:

Scale: NONE
Date: 08/02/85
Dwg. Code:
Sheet reference number: M-5
Inv. No. DACA56-86-B-0029
Cont. No. DA A56-86-C-0067
Sheet 47 of

D C B A

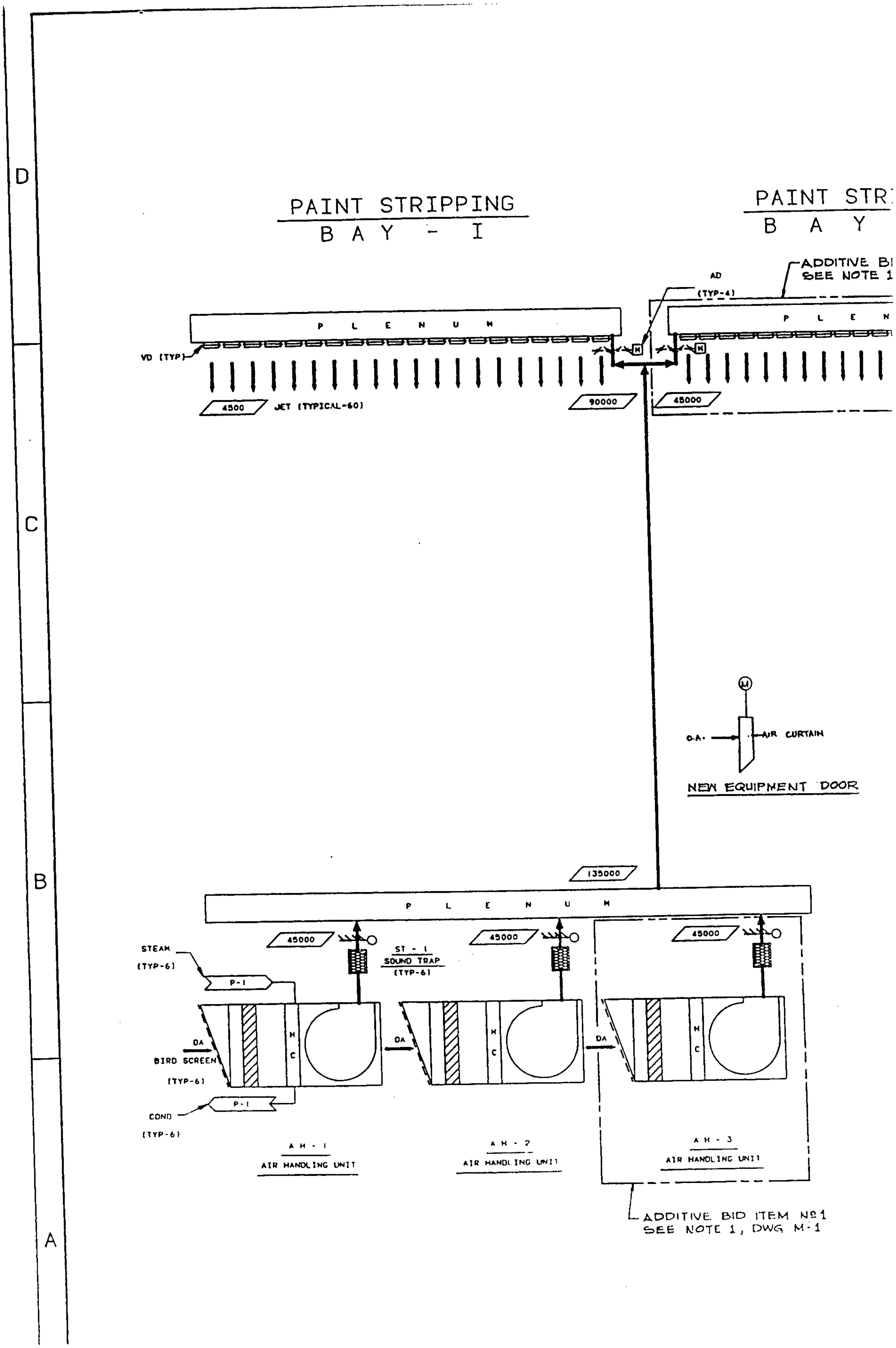
2

DRAWING OF WORK AS BUILT

TS - 2122 - F 12 - 093

Figure 19. Schematic of the Exhaust-Fan Configuration in Building 2122 at Tinker AFB.

3


D
C
B
A
PAINT STRIPPING
BAY - I
PAINT STR
B A Y
ADDITIVE BI
SEE NOTE 1
AD
(TYP-4)
P L E N U M
VD (TYP)
4500
JET (TYPICAL-60)
90000
45000
O.A.
AIR CURTAIN
NEW EQUIPMENT DOOR
135000
45000
ST - 1
SOUND TRAP
(TYP-6)
STEAM
(TYP-6)
P-1
OA
BIRD SCREEN
(TYP-6)
COND
(TYP-6)
H
C
AH-1
AIR HANDLING UNIT
AH-2
AIR HANDLING UNIT
AH-3
AIR HANDLING UNIT
ADDITIVE BID ITEM №1
SEE NOTE 1, DWG M-1
①

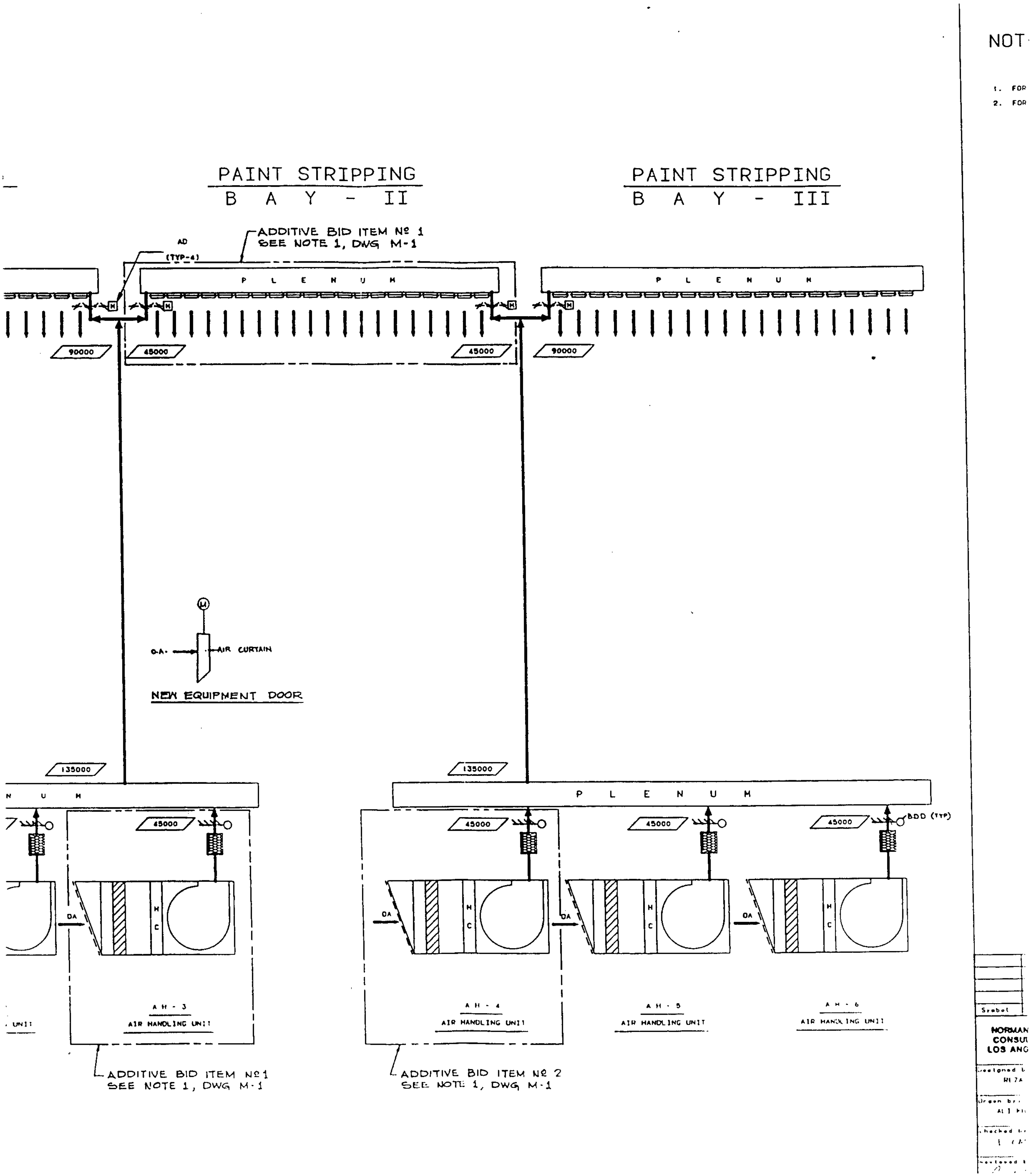


Figure 20. Schematic of Configuration

②

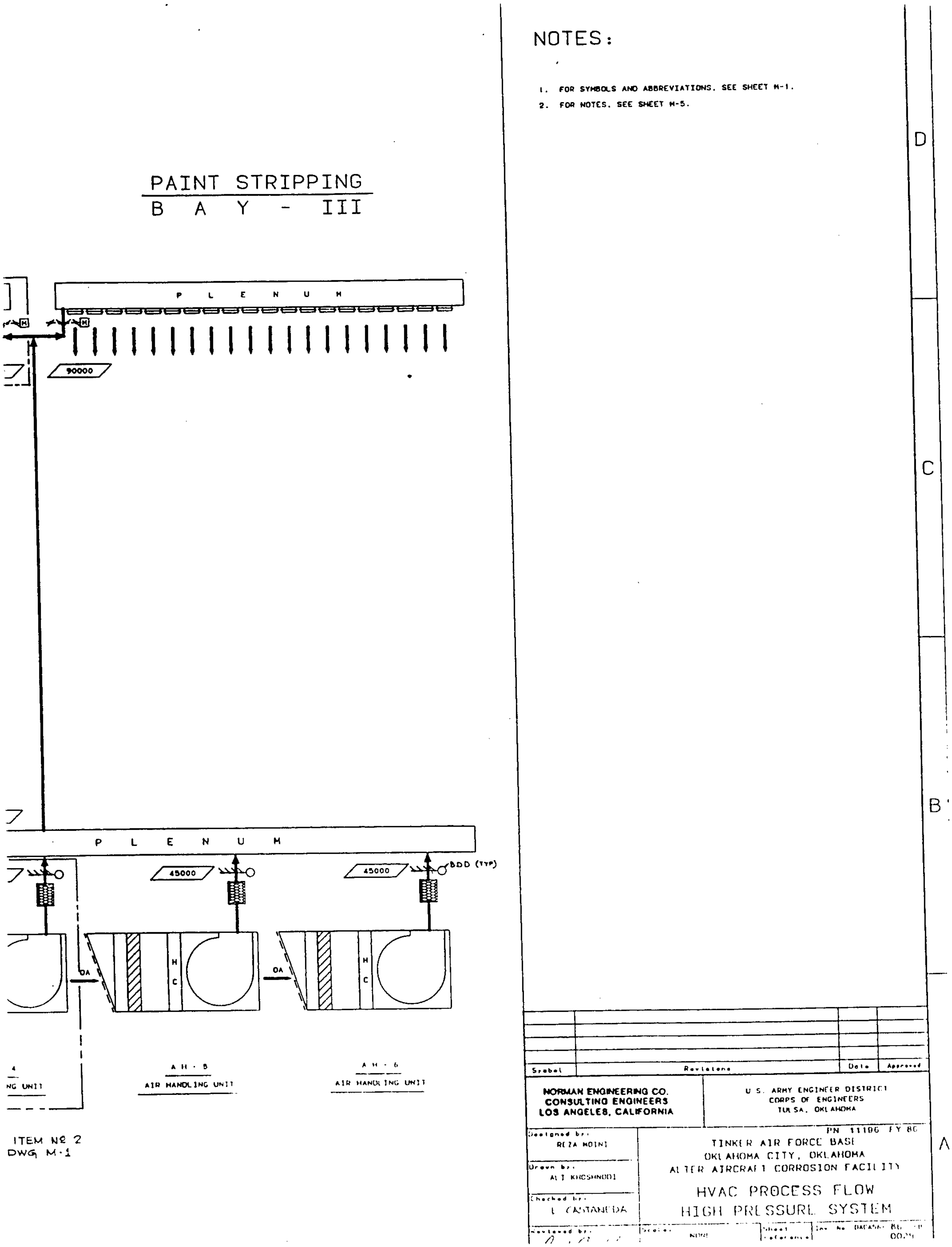
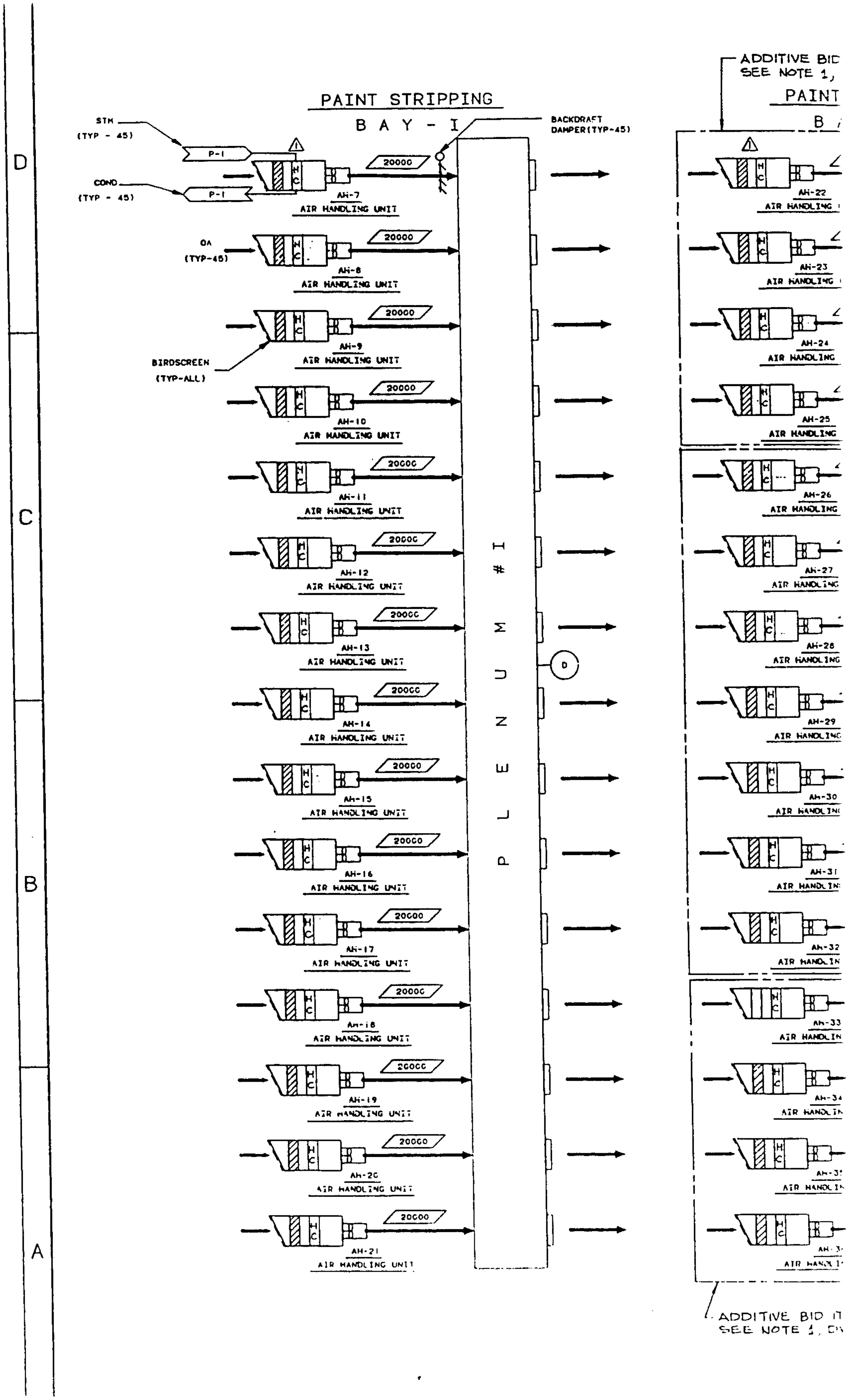


Figure 20. Schematic of the High-Pressure Makeup-Air Fan Configuration in Building 2122 at Tinker AFB.

3


PAINT STRIPPING
BAY - I
STM
(TYP - 45)
COND
(TYP - 45)
P-1
OA
(TYP-45)
BIRDSCREEN
(TYP-ALL)
BACKDRAFT
DAMPER(TYP-45)
20000
AH-7
AIR HANDLING UNIT
AH-8
AIR HANDLING UNIT
AH-9
AIR HANDLING UNIT
AH-10
AIR HANDLING UNIT
AH-11
AIR HANDLING UNIT
AH-12
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AH-19
AIR HANDLING UNIT
AH-20
AIR HANDLING UNIT
AH-21
AIR HANDLING UNIT
PLENUM #I
D
ADDITIVE BID
SEE NOTE 1,
PAINT
AH-22
AH-23
AH-24
AH-25
AH-26
AH-27
AH-28
AH-29
AH-30
AH-31
AH-32
AH-33
AH-34
ADDITIVE BID
SEE NOTE 1,
D
C
B
A

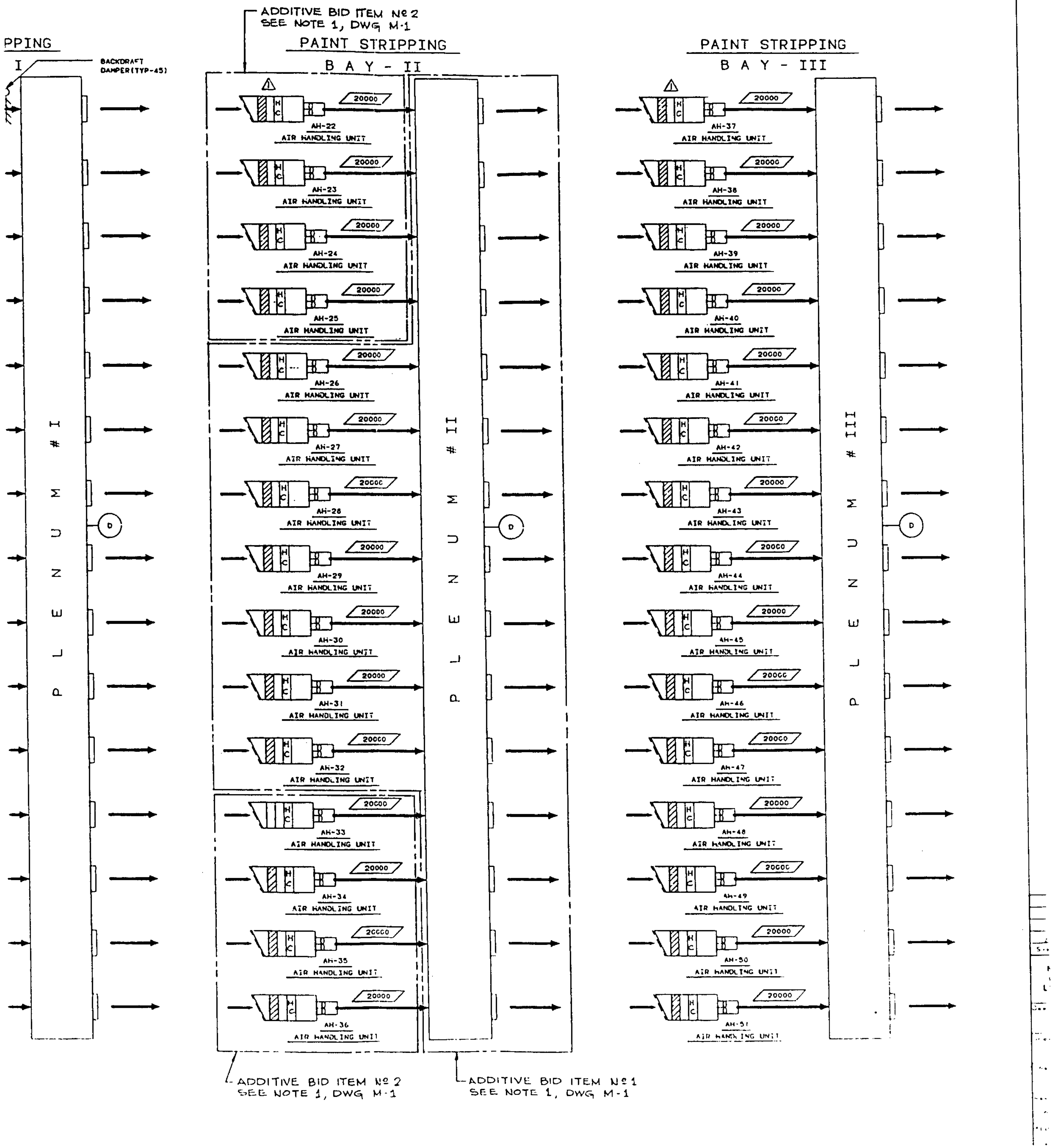

Figure 21. Schematic Configurat

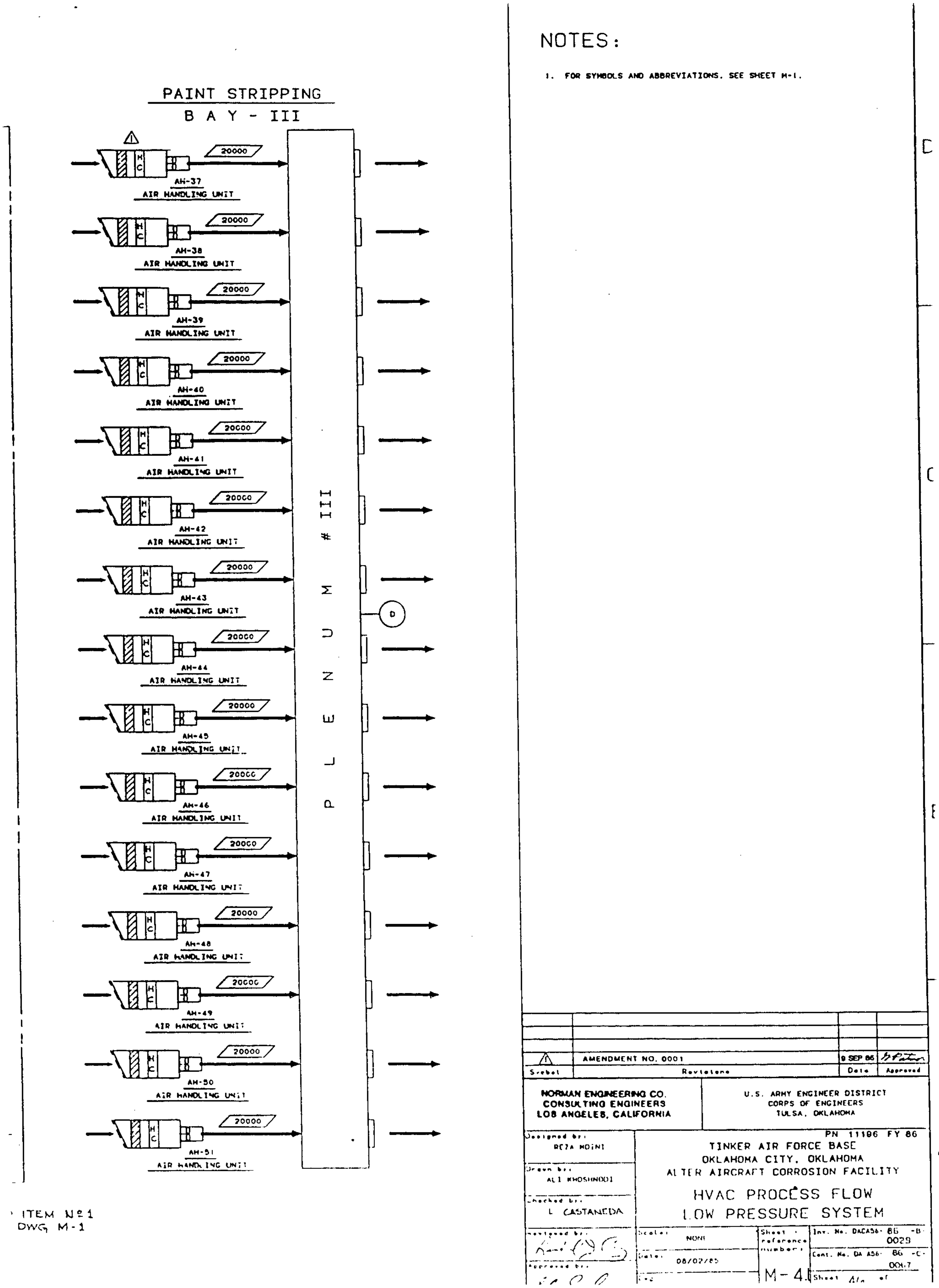

Figure 21. Schematic of the Low-Pressure Makeup-Air Fan Configuration in Building 2122 at Tinker AFB.

3

2. Potential Flow-Reduction Strategies

Two of the five flow-reduction strategies discussed in Section V.A, split-flow recirculation and external-flow reduction, are considered to be potentially effective flow-reduction strategies for Building 2122. Among the recirculation options, split-flow recirculation would least increase the building-air concentrations of MC. External flow reduction using adsorption techniques will not affect the building-air MC concentration. Split-flow recirculation is likely capable of reducing the exhaust air flowrate by 50 percent at most. This would still mean that about 220,000 cfm of MC-contaminated air would require treatment. This can be performed using an adsorption bed to treat the exhaust-air split as shown in Figure 19.

a. Split Flow with Recirculation

Implementing split-flow recirculation requires that the concentration gradients of MC in the depainting facility be well understood. Based on the MC-concentration profile at the exhaust face of the hangar, the exhaust-volume flowrate, and the height of the exhaust face on the hangar wall, the height of the partition to effect the split flow can be determined from the following mass balance (1):

$$a = \frac{MXH}{CQ} \tag{1}$$

where:

- a = Partition height, *i.e.*, distance from the top of the exhaust plenum to the horizontal partition, ft
- M = Total Mass-release rate of MC, lb/hr
- X = Fraction of the total mass of MC above the partition
- H = Exhaust-face height, ft
- C = Concentration of MC in the recirculated stream, lb/ft^3
- Q = Total volume flowrate of exhaust air, ft^3/hr

The adjustable parameter that determines the partition height and, thereby, the percent recirculation, is the concentration of MC in the recirculated stream. The higher the allowable concentration in this stream, the greater the amount that can be recirculated.

The key to obtaining effective split flow is maximizing the amount of contaminant leaving with the lower stream. This is generally a straightforward exercise for paint booths because paint aerosol readily settles. However, in an MC-stripping operation, MC aerosols are not produced. The MC in the hangar air is in the vapor phase. As such, the effects of molecular

diffusion counter the effects of gravity. The likely result is small vertical concentration gradients of MC in a stripping operation.

To achieve useful split-flow recirculation in a stripping bay in Building 2122, the following steps are suggested:

1. Measure MC concentrations at various locations in the entire bay during the depainting of an aircraft to obtain detailed temporal and spatial MC-concentration profiles.
2. Reconfigure makeup air vents and direct diffusers to effect a downward flow across the surface of the aircraft.
3. After Step 2, measure MC concentration across the exhaust face and calculate the split height based on a mass-balance equation similar to Equation 1.
4. Repeat Steps 2 and 3 until an optimum split height is obtained.
5. After an optimum split height is obtained, reconfigure the exhaust face fans to distribute the volumetric flowrate for recirculation. With the present number of fans, recirculation can be achieved in increments of 110,000 cfm. If intermediate levels of recirculation are required for optimum distribution, new fans may need to be installed.

The main cost elements incurred in the implementation of split-flow recirculation are summarized in Table 25. The overall capital cost to implement split flow with recirculation in all three bays of Building 2122 is expected to be about $1.2M. Of course, this cost, as well as the elements comprising this cost given in Table 25, are only ROM estimates. However, these estimates can be refined after the detailed MC-concentration distribution in the building has been

TABLE 25. COST ESTIMATE FOR SPLIT-FLOW RECIRCULATION IN BUILDING 2122.

Item	ROM Cost Estimate ($)
Emission characterization: ambient MC measurements	300,000
Ductwork: relocation, reconfiguration, and new additions	200,000
Exhaust fans: relocation, reconfiguration, and new additions	100,000
Exhaust-side wall: new construction and reconfiguration	500,000
MC-detection systems, flow-control systems, and instrumentation	100,000
Total	**1,200,000**

measured. It bears noting that the MC-concentration gradients in the building will likely vary somewhat with the type (size and shape) of the aircraft depainted. If more than one type of aircraft is depainted in a given bay, a variable split-flow mechanism may be called for. This could significantly increase the cost of implementing a scheme for split-flow recirculation.

b. Adsorbers

As discussed above, concentration of the exhaust-air flow can be achieved using adsorption processes. Each exhaust fan in Building 2122 is presently connected to its own stack. Thus, the flexibility exists to capture the MC in the exhaust-air stream from each fan separately, or to combine fan discharges and capture the MC from the combined exhaust stream.

The ROM capital cost to install a VOC-adsorption system (either carbon-bed or zeolite rotary concentrator) to treat an exhaust air flowrate of 450,000 cfm is about $4.5M, as discussed in Section IV.D.

c. Split-Flow Recirculation with Adsorption

The expectation is that split-flow recirculation alone can achieve, at best, a 50-percent flow reduction (about 220,000 cfm will be recirculated). If the split-flow strategy is combined with a downstream adsorber, total MC-control costs can be reduced. Figure 22 illustrates this concept. If only 220,000 cfm of the exhaust-air flowrate after split-flow recirculation requires treatment, the total capital cost of this MC-control process will be about $3.4M — $1.2M for split flow, plus $2.2M for the adsorption system (at $10/cfm as cited in Section IV.D).

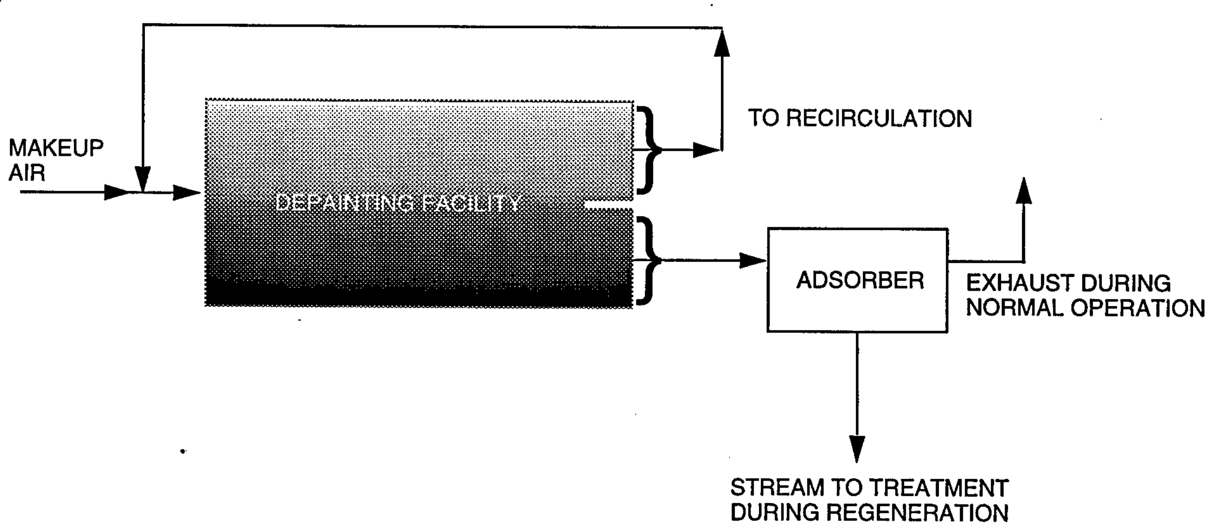

Figure 22. Split Flow with Recirculation and Adsorption.

Table 26 is a comparison of the costs for flow reduction and MC control using the three strategies discussed above. The total cost of MC control is also given in Table 26, with the addition of a thermal oxidizer as the final treatment step to destroy the desorbed MC produced during adsorbent regeneration.

In Table 26, the annual operating cost (AOC) for split-flow recirculation is not considered because it is not expected that the cost of operating the modified ventilation system will be significantly affected. Ventilation-related utility costs, which are small, were estimated as part of the facility-operating cost in Section III, and are considered in the full life-cycle-cost analysis discussed in Section VI.

According to Table 26, MC-treatment costs are as follows: The capital cost of using the adsorber alone is the highest, at about $5M. The capital cost for split-flow recirculation

TABLE 26. COMPARISON OF CAPITAL AND OPERATING COSTS FOR CONTROL OF MC USING THREE DIFFERENT FLOW-REDUCTION STRATEGIES AND THERMAL OXIDATION.

Cost Item[a]	Split-Flow Recirculation	Adsorber (Carbon Bed)	Split-Flow Recirculation with Adsorber (Carbon Bed)
Flow reduction			
1. CI[b] ($)	1,200,000	4,550,000	1,200,000 + 2,250,000
2. AOC[b] ($)	0	728,000	0 + 360,000
Regenerative thermal oxidizer			
Inlet flowrate (cfm)	225,000[c]	12,000[d]	5,600[d]
3. CI[e] ($)	1,800,000	480,000	225,000
4. AOC[e] ($)	1,350,000	96,000	45,000
Total			
CI (1+3) ($)	3,000,000	5,030,000	3,675,000
AOC (2+4) ($)	1,350,000	824,000	405,000

[a]CI = Capital investment, AOC = Annual operating cost.
[b]See Table 9.
[c]Assuming total inlet flow to adsorber = 225,000 cfm.
[d]Assume 40:1 reduction.
[e]See Section IV.B.2.b.

is the lowest, at about $3M. The combined approach, using split-flow recirculation with adsorption, has an intermediate capital cost of about $3.7M. The annual operating cost is the lowest for split-flow recirculation with adsorption, at about $0.40M, followed by adsorption alone, at about $0.82M; and, at the high end, split-flow recirculation, at about $1.35M.

C. REFERENCE FOR SECTION V

1. Ayer, J., and Darvin, C. H., <u>Cost Effective VOC Emission Control Strategies for Military, Aerospace, and Industrial Paint Spray Booth Operations: Combining Improved Ventilation Systems with Innovative, Low Cost Emission Control Technologies</u>, Paper 95-WA77A.02, AWMA 88th Annual Meeting and Exhibition, San Antonio, Texas, June 1995.

SECTION VI

LIFE-CYCLE COSTS FOR CONTINUED USE OF METHYLENE CHLORIDE VERSUS CONVERSION TO ALTERNATIVE TECHNOLOGIES

A. DISCUSSION

In this section, the full life-cycle costs of various alternatives for complying with the proposed aerospace-rework NESHAP are discussed. The life-cycle-cost analysis uses the case where 50 KC-135 aircraft are depainted annually in a facility similar to that of Building 2122 at OC-ALC.

In Section III, the annual operating costs for MC-based depainting and four alternative processes were summarized. In Section IV, the costs of controlling MC emissions to levels required by the aerospace-rework NESHAP were estimated. In Section V, the costs to effect exhaust-air flow reduction from a large-aircraft depainting facility were discussed. By combining the cost estimates outlined in Sections III, IV, and V, the costs of continuing to use the MC-based aircraft-stripping process with emission controls to meet the aerospace-rework NESHAP can be estimated. Similarly, the costs of converting to the various alternative processes considered in this study can also be estimated. Table 27 summarizes the estimated capital investment and annual operating costs for each of the various depainting options considered. The data in the table show that the capital-investment (CI) costs for controlling MC emissions to the level required by the aerospace-rework NESHAP are comparable to the capital cost of converting to a LARPS or a laser-based depainting process. The capital costs to switch to an MPW/BOSS process with BA presoftening are lower. Converting to a two-component BA process is the least-expensive option in terms of capital costs because substantial modifications to an existing MC-based process are not required.

The estimated annual operating costs (AOCs) given in Table 27 are the lowest, at about \$528,000, for the LARPS and laser processes, followed by the \$912,000 AOC for the MPW/BOSS process with BA presoftening. The AOC for the controlled MC process is about \$1.49M, and for the two-component BA process is about \$1.77M.

The CI and AOC costs in Table 27 can be combined to yield a complete life-cycle-cost estimate for each NESHAP-compliance option. Such an analysis provides the total costs of a process over its useful life. For the purpose of this study, the life cycle of each of the five processes considered is assumed to be 10 years. This may seem to be too short a lifetime, but considering trends towards stricter environmental standards for chemical usage, and rapid developments in robotics and computer-based process controls, 10 years without significant

TABLE 27. DEPAINTING PROCESS COST SUMMARY.

Aircraft Type: KC-135 **Emission Control System Operation = 5,000 hr/yr**
Aircraft Surface Area = 9,600 ft^2
Depainting Bay Exhaust-Air Flowrate = 450,000 cfm
Number of Aircraft Depainted Annually = 50

Cost Item	MC (Baseline)	Two-Component BA	MPW/BOSS with BA Presoftening	LARPS	Laser Stripping
Capital investment (CI)					
1. Implementation in existing facility (%)[a]	0	50,000	100,000	4,000,000	4,000,000
2. Flow reduction ($)[b]	3,475,000	0	0	0	0
3. Exhaust air treatment ($)[b]	225,000	0	0	0	0
4. Air-stripper for MC from discharge water ($)[c]	50,000	0	0	0	0
Total CI (1 + 2 + 3 + 4) ($)	3,750,000	50,000	1,000,000	4,000,000	4,000,000
Annual operating cost (AOC)					
Depainting cost ($/ft^2)[d]	3.0	3.7	1.9	1.1	1.2
Annual area depainted (ft^2)	480,000	480,000	480,000	480,000	480,000
5. Depainting AOC ($)[d]	1,440,000	1,776,000	912,000	528,000	576,000
6. Flow reduction AOC ($)[b]	0	0	0	0	0
7. Exhaust air treatment AOC (%)[b]	45,000	0	0	0	0
8. Air stripper AOC ($)[c]	10,000	0	0	0	0
Total AOC (5 + 6 + 7 + 8) $	1,495,000	1,776,000	912,000	528,000	576,000

[a]Section II.B.
[b]Table 26.
[c]Table 24.
[d]Table 17.

modifications can be considered a reasonable lifetime for any of the depainting technologies evaluated. To compare the life-cycle cost of each of the five options, the total present value of the expenditure stream to implement each process is estimated. The straightforward escalation procedures used in Section III are not used here. Instead, the DoD 10-percent interest rate for discounting is used. The DoD 10-percent factor is adjusted for the general inflation rate for the period over which it is applied and, thus, represents the "real rate" of interest. The 10-percent discount factor for 10 years is 6.145, as calculated from the cumulative uniform series factor formula (1):

$$DF = \frac{(1 + r)^n - 1}{r(1 + r)^n} \tag{2}$$

where:

DF = Discount factor

r = Effective annual discount rate, 10 percent

n = Number of years, 10 years

The total present value (TPV) of any option is then defined by the formula

$$TPV = CI + AOC \cdot DF \tag{3}$$

If the life cycle of each option is assumed to be different (different DF), comparisons among options should be made in terms of the uniform annual cost (UAC). The UAC is defined as

$$UAC = \frac{TPV}{DF} \tag{4}$$

Table 28 summarizes the results-of the life-cycle-cost calculations. The information in the table indicates that the MPW/BOSS process with BA presoftening is the least-expensive option on both a TPV and UAC basis, followed by the LARPS and laser processes. However, the estimated life-cycle costs for these three processes are not significantly different. The MC-based process incorporating emission controls is the most-expensive option, followed by the two-component BA process. In addition to the cost, another factor that must be considered is the potential for changing (increasing) the production rate of the stripping process. The overall change in production rate that could be realized by adopting alternative stripping processes is summarized in Table 12. Table 29 lists the UAC from Table 28 and the potential capacity change

TABLE 28. LIFE-CYCLE-COST ANALYSIS.

Cost Item	MC (Baseline)	Two-Component BA	MPW/BOSS with BA Presoftening	LARPS	Laser Stripping
1. Capital investment (CI) ($)	3,750,000	50,000	1,000,000	4,000,000	4,000,000
2. Annual operating cost (AOC) ($)	1,495,000	1,776,000	912,000	528,000	576,000
3. 10-year discount factor (DF)	6.145	6.145	6.145	6.145	6.145
Total Present Value (TPV) ($) TPV = CI + DF x AOC	12,937,000	10,964,000	6,604,000	7,245,000	7,540,000
Uniform Annual Cost (UAC) ($) UAC = TPV/DF	2,105,000	1,784,000	1,075,000	1,179,000	1,227,000

TABLE 29. COMPARISON OF DEPAINTING PROCESSES — COST AND CAPACITY.

Parameter	MC (Baseline)	Two-Component BA	MPW/BOSS with BA Presoftening	LARPS	Laser Stripping (One 2-kW Laser)
UAC ($)	2,105,000	1,784,000	1,075,000	1,179,000	1,227,000
Increase in number of aircraft depainted	0	5	26	50	-19

for each process from Table 12. From Table 29, it can be seen that the LARPS process projects to be the most economically efficient process, followed by MPW/BOSS process with BA presoftening.

B. REFERENCE FOR SECTION VI

1. Economic Analysis Handbook, NAVFAC P-442, Naval Facilities Engineering Command, Alexandria, Virginia, 1986.

SECTION VII
CONCLUSIONS

MC-based paint stripping is extensively used by the AF to strip aircraft frames of Boeing manufacture, specifically KC-135, E-3, B-1, and B-52 aircraft. At present, MC emissions to the atmosphere in the exhaust air from stripping facilities are not controlled. However, by the effective date of the aerospace rework NESHAP, 1 September 1998, MC emissions from MC-stripping processes will have to be reduced by at least 95 percent via the application of MC-control processes or the use of alternative stripping processes that do not generate HAP emissions.

The AF is currently evaluating several alternative stripping processes, including a two-component BA-stripping process, MPW/BOSS after presoftening with BA, and LARPS with HPW. Of these, the two-component BA process has the fewest potential operational concerns. Both MPW/BOSS after presoftening with BA and LARPS with HPW suffer from intrusion of the aqueous stripping medium (water with BOS or water alone) into seams and cracks in the stripped substrate, along with removal of sealant material with the stripped paint. However, the two-component BA process is substantially more costly than the baseline MC process without VOC controls.

Several MC-control approaches can be used to achieve the NESHAP-mandated 95-percent reduction should MC stripping continue to be used. These include thermal oxidation, with or without exhaust MC concentration using activated carbon, polymer, or zeolite adsorption, and UV/ozone oxidation with carbon adsorption as a final polish. These control approaches can also be augmented via a variety of internal gas-discharge-stream flow-reduction strategies ranging from simple flow recirculation through exhaust split flow with recirculation.

Of the MC-destruction processes, the thermal oxidation processes using regenerative thermal oxidizers or catalytic oxidizers, with adsorption concentration, have the most-extensive experience base of successful, effective VOC control. A few UV/ozone processes have been installed on paint booths, but there are no publicly available data from full-scale installations on the effectiveness of the UV/ozone process itself in destroying VOC contaminants in gas discharges. All publicly available full-scale performance data are in terms of final system discharge concentration measurements taken downstream of carbon adsorbers that treat the gas exiting the UV/ozone system. Because the UV/ozone process relies to a significant extent on

destroying VOCs absorbed into an aqueous solution, expectations are that the destruction process would not be particularly effective in destroying MC in stripping-process exhaust.

A procedure to estimate the full life-cycle costs of alternative approaches to complying with the aerospace-rework NESHAP was developed and used to assemble life-cycle-cost estimates for a number of approaches to bringing Building 2122 at OC-ALC, the largest MC-stripping operation within the AF, into compliance with the NESHAP. Of the five approaches evaluated, replacing the MC-stripping process with either MPW/BOSS after presoftening with BA, LARPS with HPW, or laser stripping had the lowest and comparable UAC, of \$1.1 million to \$1.2 million. Implementing the two-component BA process had an intermediate UAC of \$1.8 million. The option with the highest UAC, at \$2.1 million, was continuing to employ MC stripping while implementing a control approach comprising 50-percent flow reduction via split-flow recirculation, with control of the decreased exhaust flow accomplished via carbon adsorption with thermal oxidation of the carbon-regeneration stream.

These results suggest that the most cost-effective NESHAP compliance strategy will indeed be to eliminate MC-based stripping within the AF and adopt one or more alternative processes. However, this analysis presupposes that all options produce an equivalent surface, including the same susceptibility to corrosion, and includes the same costs to attend to peripheral effects. Of the least-expensive options, the aqueous-stripping-medium processes (*i.e.*, MPW/BOSS after presoftening with BA, and LARPS with HPW) suffer possible substrate-damage problems. The process holding the promise to avoid these problems while still being a least-expensive option is laser stripping. However, this process has yet to be demonstrated.

Perhaps the best overall strategy incorporates switching to the two-component BA process in the short term, to meet the NESHAP-compliance schedule, while aggressively developing the laser-stripping technology for future use. The capital costs of switching to two-component BA stripping are modest, so unrecoverable investment costs are low, while the operating costs of the laser process are projected to be low, a benefit that can be used to advantage after the laser-stripping process becomes fully developed.

APPENDIX A

ALC RESPONSES TO DEPAINTING-INFORMATION QUESTIONNAIRES

Acurex Environmental

CORPORATION

A Geraghty & Miller Company

Ms. Stacy Disco
OC-ALC/EMV, LAPEP

7/26/96

Dear Ms. Disco:

This is in response to our telephone conversation on Friday, July 26, 1996. We are currently estimating true life-cycle costs of controlling methylene chloride in aircraft depainting versus alternative processes. This project is being performed for the USAF under the oversight of the Environics program manager Dr. Joe Wander of Armstrong Laboratory, Tyndall AFB, FL. We are in the process of collecting data related to methylene chloride depainting facilities, especially for aircraft frames, from various ALCs. Capt. Dena Maher suggested that you may be able to help us in our efforts at OC-ALC.

On your suggestion I am attaching a list of questions that will help us get a preliminary idea about the MC depainting operations at OC-ALC. In the near future we will be visiting each of the ALCs to collect more exhaustive data. Please treat the attached questionnaire as a preliminary data form. In case you are not able to respond to a question I would appreciate it if you are able to direct me, if possible, to an appropriate source. Thank you for your help in this matter. I can be reached at (415) 254-2486 if you have any questions.

Sincerely,

Shyam Venkatesh

Shyam Venkatesh, Ph.D
Staff Engineer
Acurex Environmental Corp.
Mountain View, CA 94039
Tel: (415) 254-2486
Fax: (415) 254-2497

FAX

Date: 08/15/96

Number of pages including cover sheet: 5

To:

Shyam Venkatesh

Phone: 415-254-2486

Fax phone: 415-254-2497

CC:

From:

Stacey Disco

Phone: 405-736-5986

Fax phone: 405-736-4178

REMARKS: ☐ Urgent ☒ For your review ☐ Reply ASAP ☐ Please comment

Shyam,

Here is the information you requested regarding your survey. I apologize for taking so long.

Thanks,

Stacey Disco

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AIRCRAFT DEPAINTING USING MC - PRELIMINARY DATA QUESTIONNAIRE

1. B-52 and KC-135 aircraft

2. We have just recently begun stripping B-52s and do not have an estimate on how many we are depainting per year.

   We strip approximately 65 to 70 KC-135 per year.

3. A/C frames: 12 to 15- 55 gallon drums
   A/C components: 10 to 15 - 55 gallon drums

4. 2 Hangers presently with one a/c per Hanger. May be as many as 4 stripping areas for parts around each a/c.

5. Entire area of both hangers combined is approximately 100 yd. x 65 yd..

6. MC - 50%
   Phenol - 20%
   Other organic components - ?
   Inorganic additives - ?

7. KC-135: approximately 7/24 hour shift ; 2 days 42 PE ; approximately 336 hours
   B-52: approximately 10 /24 hour shift ; 2 days 60 PE ; approximately 52 hours
   (Note: These figures are for polyurethane or one coat. The numbers could triple if the plane has koroflex primer)

8. Hard cap fresh air, full wet suit , neoprene gloves, protective sleeves, and rubber boots

9. Total duration in one day: 6.5 to 7 hours
   Length of each stay: 2 hours

10. KC-135: 7,000 to 10, 000 gallons
    B-52: 15,000 to 20,000 gallons

    Note: The two a/c used in this process are rinsed off with water hoses with no way to gauge how many gallons/year. These are pure estimates.

11. Part a. Exhaust system's puling fumes out of hanger. Approx. 3 in each hanger.

    Part b. Air exhaust only

12. Containment methods - All three hangers (only two in use) have a deep though surrounding the stripping area. All waste drains into this trough. Solids are collected at the bottom and liquids are drained to the Industrial Waste Treatment Plant.

    Collection Methods - Sludge and solids at the bottom of the trough are cleaned out by contractors and the waste is put into 55 gallon drums.

7

13. Our employee's are supplied with fresh air apparatuses run by a generator. The air passes through an alarm (purifying) system which monitors the quality. Also, the fresh air boards which the apparatuses are connected to have their own air purifier which are changed monthly. The air in the hanger is pulled out by an exhaust system. When working in closed areas or confined spaces, an LEL check is make every four hours.

Venkatesh,Shyam

From:	Venkatesh,Shyam
To:	koconnor
Subject:	A/C depainting Information
Date:	Tuesday, August 27, 1996 1:37PM

Kevin O'Connor
OC-ALC/EM, Tinker AFB
8/27/96

Kevin:

Thank you for your help. This is a follow up to our conversation earlier today. As I mentioned to you on the telephone, the information I need is a project for ENVIRONICS, Armstrong Labs, Tyndall AFB. The project officer is Dr. Joe Wander at AL. We are trying to estimate true life-cycle costs of controlling methylene chloride (MC) in aircraft depainting versus alternative processes. To this end I am looking for the following information in a preliminary manner. A similar questionnaire has been circulated to other ALCs.

Ms. Stacy Disco responded to the questionnaire sent to OC-ALC. In that response it was indicated that KC-135s and B-52s were being depainted using MC. During our conversation you had mentioned that this was not the case. I am repeating a few of those questions for further clarification

The aerospace NESHAPS require that 1996 and 1997 be treated as the baseline years to affect any changes for the purpose of control/abatement. Therefore, I would appreciate it if your data reflects at the latest 1995 and if possible projected information for 1996.

(1) Which a/c frames are being currently depainted using MC?

(2) How many of each aircraft type are depainted per year?

(3) How much MC is used per A/C of each type? What was the total usage in 1995? Projected usage in 1996? What is the split between components and a/c frames?

(4) What A/C will be phased out of MC depainting through high pressure water LARPS or any other alternative technology?

(5) Could you briefly describe the depainting facility for each A/C type (MC only):
(for e.g., hangar/booth, open/closed, dimensions etc.)

(6) The objective of this project is to also evaluate the feasibility of retrofitting an air pollution control system for MC control. With this in view, could you briefly describe the exhaust/ventilation at each of the MC depainting hangar/bay?
(for e.g. - No. of exhaust fans over each depainting area, air flow rates, is there a single exhaust stack for the entire facility? fan capacity, etc.)

I would greatly appreciate your comments/suggestions in connection with the above questions and specifically concerning the feasibility of retrofitting an air pollution control system for MC control/abatement at the current facilities.

Once again thank you very much for your help.

Sincerely,
Shyam Venkatesh
Project Engineer
Acurex Environmental Corp., Mountain View, CA 94039
T: (415) 254-2486 F: 254-2497
e mail: GMGWWEST!MTNVIEW!SVENKATESH@gmdenver.attmail.com

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Venkatesh,Shyam

From: O'Connor, Kevin
To: SVENKATESH
Subject: RE: A/C depainting Information
Date: Tuesday, September 03, 1996 2:33PM

Sorry for the delay.

We currently strip aircraft in two facilities: building 2122 (our wash rack) and building 2280 (our paint hangar). Due to the height requirements of the E-3 aircraft it must be stripped in paint hangar.

1) -135 a/c , B-52 a/c and E-3 a/c
2) we have just started stripping B-52, projected B-52 strip workload is 17-20/yr
historically we strip 45-55 -135 a/c per yr
historically we strip 8-12 E-3 a/c per yr
3) estimate: 12-15 barrels per aircraft with the most difficult Koroflex primed a/c requiring up to 25 barrels worst case scenario - all aircraft
total usage of meth chloride based strippers was about 80-90,000 gallons
same estimate for 1996 usage
80% to airframes / 20 % to components
4) LARPS utilizes high presssure water and will eliminate the requirement to strip approximately 40-50% of the -135 a/c workload and all B-1 a/c starting in mid-97. A second LARPS may become available in the out years to strip E-3 and B-52. Alternatives strippers are also being aggressively pursued. Because of the impending environmental regulations, tinker plans to be out of the meth chloride stripping business by Sep 98.
5) building 2122 is a three-bay wash rack. Only two bays are used for chem stripping
building 2280 is a two bay paint hangar. Only one bay is used to strip E-3 a/c.
each hangar has two bay area of about 100 yds x 65 yds - approximation
6) please contact Jerald Terrel, OC-ALC/LAPEE, our facilities engineer at 405-736-7757.

Kevin O'Connor

From: SVENKATESH
To: koconnor
Subject: A/C depainting Information
Date: Tuesday, August 27, 1996 2:45PM

Kevin O'Connor
OC-ALC/EM, Tinker AFB
8/27/96

Kevin:

Thank you for your help. This is a follow up to our conversation earlier today. As I mentioned to you on the telephone, the information I need is a project for ENVIRONICS, Armstrong Labs, Tyndall AFB. The project officer is

Dr. Joe Wander at AL. We are trying to estimate true life-cycle costs of controlling methylene chloride (MC) in aircraft depainting versus alternative processes. To this end I am looking for the following information in a preliminary manner. A similar questionnaire has been circulated to other ALCs.

Acurex Environmental

C O R P O R A T I O N

A Geraghty & Miller Company

8/22/96

Ms.Jeannie Warnock
Environmental Engineer
SM-ALC

Dear Ms. Warnock:

This is a follow-up to our telephone conversation earlier today. We are currently estimating true life-cycle costs of controlling methylene chloride in aircraft depainting versus alternative processes. This project is being performed for the USAF under the oversight of the Environics program manager Dr. Joe Wander of Armstrong Laboratory, Tyndall AFB, FL. We are in the process of collecting data related to methylene chloride depainting facilities, especially for aircraft frames, from various ALCs.

Attached please find a list questions, responses to which will greatly help us in our data collection efforts. I would like to speak with you concerning this at a time that is convenient to you. I appreciate your help very much in this matter. I can be reached at (415) 254-2486 if you have any questions.

Sincerely,

Shyam Venkatesh

Shyam Venkatesh, Ph.D
Project Engineer
Acurex Environmental Corp.
Mountain View, CA 94039
Tel: (415) 254-2486
Fax: (415) 254-2497

555 Clyde Avenue, P.O. Box 7044 • Mountain View, California 94039 • (415) 961-5700 • FAX (415) 254-2497/2496

10/1/96
Jeannie Warnock
1:30pm

AIRCRAFT DEPAINTING USING MC - PRELIMINARY DATA QUESTIONNAIRE

1. Types of aircraft being depainted using MC?

   KC-135 whole airframe

2. Number of aircraft being depainted using MC (per year) 20 ?

3. Approximately how much MC is consumed for :
   - aircraft frames ________? } 500-800 gal/aircraft
   - aircraft components________? ~~Cannot~~ ~~tell~~ Does not know distribution

4. How many depainting areas exist within one building/hangar ~~depainting 1 bldg~~.? 11 locations for parts.

5. Approximate dimensions of a depainting area, or entire facility?

   38,000 sq ft 260 x 140

6. Composition of MC based stripper:
   MC - 40-50%
   Phenol- 5-15%
   Other organic components- %
   Inorganic additives- %

   They use phenolic (no non-phenolic)

7. How many personnel are required for the depainting process?

Aircraft Type	# of Personnel	Total Hours for MC depainting
KC-135	6-8/shift	Prep Time: 3 days Actual Depainting Time: 6 shifts to 8 shifts Deprep time: 2 days

8. (a) What is the typical "dwell" time for MC based stripper on the aircraft?

   18-30 mins

   (b) How many applications of MC are required typically?

   2-3 applications. High-end = 4

9. Please describe any personnel protection equipment and clothing used.

   Tyvex uniform; Air masks, gloves boots neoprene

10. What is the typical duration of personnel in protective clothing, respirators, etc.?
    Total duration in one day — ?
    Length of each stay — ?

11. Is water used to remove MC coating from aircraft/component surface Not during dwell time?

-How much water is used?

Aircraft type	Gallons of water
KC-135	av 20,000 gal

12. Please describe briefly current:
Air emission containment (ventilation system) methods -

None

Air emisson control (filters, carbon beds, incinerators, etc.) methods-

-None -

Ventilation (# of exhaust fans? exhaust flow rate? etc}

- None -

① Mike Proll x309

13. Please describe briefly current:
Waste sludge, depainting residue and overflow MC/water containment methods-

Contact ② Ron Stevenson x0228

Contacted Ron Stevenson x0228 10/4/96 He is the IWTP person

Typical generation of paintchips sludge, precipitate, etc from depainting facility is 2 drums a week.

collection methods-

MC concentration (- he thinks -) in the wastewater ranges from 100ppm to 1,000ppm.

storage methods-

Disposal thro' DRMO

disposal methods-

disposal costs:

14. What are the current air monitoring methods used during depainting operations?
none - In 1992 CH2M Hill conducted a study

15. What is the concentration of chemical stripper in the air exhaust stream (ppm) ?
— do not know -

16. Is the MC based stripper a commercial product?
Name:_____________ TO-1-1-8.
Cost per unit:_____________ CEE BEE products 256 & 458

Acurex
Environmental
CORPORATION *A Geraghty & Miller Company*

FAX MEMORANDUM

To: **Mr. Billy Barrett**
Batelle
101 Park Drive
Warner Robins, GA 31088
Tel: (912) 328-6630
Fax: (912) 328-6680

October 15, 1996

From: Shyam Venkatesh
Acurex Environmental Corporation
555 Clyde Avenue
Mountain View, CA 94039
Tel: (415) 254-2486
Fax: (415) 254-2497/2496

Attached please find a questionnaire/information sheet. This is for a project titled "*Control Technology for Depainting Operations - Estimation of True Life-Cycle Costs of Controlling Methylene Chloride (MC) in Aircraft Depainting Versus Alternate Processes,*" Contract No: F08637 95 D6003, ID/IQ Tech Area 3, issued by Armstrong Laboratory. Project Officer is Dr. Joe Wander. It is a joint project between Acurex and Battelle, with Acurex taking the lead.

Currently methylene chloride is being used to depaint aircraft frames mainly at McClellan (Sacramento) and Tinker (Oklahoma City) AFBs. Both these bases are actively looking at replacing MC and/or controlling it in order to comply with the impending NESHAP. The attached questionnaire is aimed at identifying current (and future) depainting methods at WR-ALC that have replaced MC based depainting operations. The questionnaire is also aimed at obtaining information that will be useful to perform a life-cycle analysis for the replacement of MC based operations at these other facilities.

Also attached is a copy of the E-mail from Bob Litt. If you have any questions please do not hesitate to call me. Thank you for your help.

Battelle
. Putting Technology To Work
Warner Robins Operations
206 Park Drive
Warner Robins, GA 31088
Telephone (912) 328-6630
Facsimile (912) 328-6680

FACSIMILE TRANSMISSION

Date: 28 Oct 96

Total Pages (excluding lead) ~~3~~ 4

Subject: Reply to Questionaire

To: Name Shyam Venkatesh

Address: Acurex

Fax Number 415-254-~~2479~~ 2497

Tele.Number 415-254-2486

From: Billy A. Barrett____

Frank Ryals______

Don Black______

Other__________

I sent this to wrong number on 28 Oct 96. Also included is an expanded description of the items in question 10 under C-130 aircraft.

Don Black

Shyam Venkatesh
Acurex Environmental Corporation
555 Clyde Ave.
Mountain View, Ca. 94039
Tel: (415) 254-2486
Fax: (415)254-2497/2496

In response to your questionnaire, the following information is provided:

Question 1:

F-15	87 acft per year ~	Plastic Media
C-141	* acft per year ~	Medium Pressure Water/Bicarbonate of Soda/BA
C-130	* acft per year ~	Medium Pressure Water/Bicarbonate of Soda

* Data to be provided at a later date.

Question 2:

F-15 2,200 sq ft X 87 acft = 191,400 sq ft per year
C-141 17,425 sq ft X acft =
C-130 12,836 sq ft X acft =

Question 3:

F-15~ MC replaced in CY89 by PMB
C-141~ MC replaced in CY 95 by MPW/BOSS
C-130~ MC replaced in CY 94 by MPW/BOSS

Question 4:

For the C-141 aircraft, a single application of BA is sprayed over the entire aircraft. The chemical is allowed to dwell for at least four hours and then is sprayed with 14,000-15,000 psi of water and bicarbonate of soda. All surfaces are completely depainted and then adequately rinsed with warm water, allowed to dry and then examined for adequacy of the stripping.

Question 5:

Key steps are (1). BA application with dwell time, (2). depaint with MPW/BOSS, (3). rinse with warm water.

Question 5.1:

BOSS alone ~600 hours.
BA plus BOSS~200 hours

Question 5.2:

Six to eight personnel are involved.

Question 5.3:

F-15 100 hours in prep 100 hours in deprep

C-141	288 hours in prep	288 hours in deprep
C-130	180 hours in prep	180 hours in deprep

Question 5.4:

	C-141	C-130	F-15
Benzyl Alcohol	165 gallons	110 gallons	---
Bicarbonate of Soda - (Varies by Aircraft)	5000 pounds	10,000 pounds	---
Water	unknown	41,314 gallons	---
Plastic media	----	----	1500-2000 pounds*

*Based on waste media estimate

Question 6:

During preparation-ear, eye and respiratory
During depainting-ear, eye, respiratory, rain gear and boots
During deprep-ear, eye, respiratory if using MEK/Toulene

Question 7:

PPE use time is 1-1.5 hours maximum use time

Question 8:

MPW/BOSS~ Aqua Miser Model 25 with media feed
Portable filtration units
Chemical application equipment (tanks, sprayers)
PMB Aerolyte Systems

Question 9:

Benzyl Alcohol - $1,100 per 55 gal drum
Soda - $16-18 per 50 pound bag
PMB - $600 per 250 pounds

Question 10:

All waste is hazardous. The liquid waste from the C-141 and C-130 operations goes to the industrial waste treatment plant. There is no liquid waste from the F-15 operation. Solid waste generated in FY96 are is as follows:

F-15. 130,500 to 174,000 pounds disposed of via contract at zero dollars of cost. A new blasting media is being used on the F-15, therefore the pounds used is an estimate. There is no disposal cost for the PMB as the supplier picks up the spent media and recycles it into other products at no cost to the government.

C-130. In the C-130 the pounds of waste cannot be divided by the number of aircraft to determine the sludge generation as other parts are also depainted in the facility. The waste is normally placed in barrels and a contractor is paid to dispose of the same. Other substances which are process waste, in addition to the percentages of chips etc., are present in the barrels.

The following information is from the Centers environmental records:

	Pounds	Cost
Trenches - 15 months of accumulation	42,606	$78,395
10-60% paint chips	12,943	6,755
70-90% paint residue	5,179	1,604

C-141. The medium pressure water and bicarbonate of soda process was introduced to the C-141 aircraft in 1995. During FY96 (1 Oct 95 - 30 Sept 96), the majority of the C-141's stripped were accomplished in an interim facility, the East Dock of building 110, as the primary C-141 facility (Bldg. 54) was undergoing modification. Data from building 110 operations would not depict the waste stream as it now is in building 54, as building 110 does not contain the same type of trenches, therefore, the chip and paint waste are gathered in each facility in different manner. The East Dock collection efficiency is less than building 54. Also, so few aircraft have been processed in building 54 that sufficient waste has not been generated to determine the amount of and cost to dispose of the same.

Question 11:

Scheduled depainting modifications of WR-ALC aircraft include the use of a water only process which will utilize a new nozzle. On selected parts/areas we are looking at the use of a barrier coating system which will aid in the depaint process.

Question 12:

Slight, if any, improvement is realized provided there are no major mechanical problems with the equipment and/or reductions in the production personnel.

Question 13:

Depainting of the C-141 aircraft is accomplished in building B-54. There are six make up fans and eight exhaust fans. The air flow is tail to the nose of the aircraft. The air flow rates are 600,000 CFM in the summer and 450,000 CFM in the winter. The waste is primarily paint chips, water, and bicarbonate of soda which goes into trenches in the floor. About 90% of the solid remains in the trenches, which are cleaned out every 12-18 months. The liquid waste from the trenches with residual paint chips goes into a 10,000 gallon lift station which has a water weir for separation of paint chips. The waste water then goes from the lift station to the industrial waste treatment plant.

Question 14:

Air flow and air samples are accomplished annually in all areas by the Base bioenvironmental engineering organization. In the F-15 area air samples are taken every 60 days in addition to the annual survey.

Trench waste sludge with solvents - Methylene chloride, xylene, toluene, MIBK, MEK, ethyl benzene, and benzene.

10-60% paint chips - 10 - 50% thinner and 1 - 10% water, xylene, acetone, MEK, toluene, methylene chloride, ethyl benzene, chromium 10 -75 ppm.

70-95% paint residue and water - 1-5% benzyl alcohol with greater than 5 ppm of chromium.

APPENDIX B

MATERIAL SAFETY DATA SHEETS

Bioenvironmental Engineering Flight

72nd Aerospace Medicine Squadron
72nd Medical Group
Tinker Air Force Base, Oklahoma

****

Date: 28 Oct 96

To: Name: Shyam Venkatesh

Number to call for pickup:

Company:

Subject: MSDS (methylene chloride (phenol stripper)

Message:

Shyam,

We determine the level of respiratory protection from personal breathing zone air sampling. Workers are required to wear a loose-hood air supplied respirator. Protection factor of 25

From: Teresa Wheeler
72 AMDS/SGPB
7701 2nd Street Suite 110
Tinker AFB, OK 73145-9200

Phone: (405) 734-7844
DSN: 884-7844

FAX: (405) 734-4241
DSN: 884-4241

Releaser Signature:______________________________

THIS TRANSMISSION CONSISTS OF 3 PAGES INCLUDING COVER SHEET

UNCLASSIFIED

ELDORADO PR-3500-19
PAINT STRIPPER

MATERIAL SAFETY DATA SHEET

0 / 2 / 0 / CORR

I. PRODUCT IDENTIFICATION

MANUFACTURER'S NAME: ELDORADO CHEMICAL COMPANY, INC.	REGULAR TELEPHONE NO. 512-653-0323 / FAX NO. 1-512-650-0828 / EMERGENCY TELEPHONE NO. 1-800-531-1088
ADDRESS: P.O. BOX 34837, SAN ANTONIO, TEXAS 78265	8010PPR-3500-19
CHEMICAL NAME OR FAMILY: CHLORINATED SOLVENT	SHIPPING NAME (DOT): CORROSIVE LIQUID, N.O.S. UN-1760
TRADE NAME AND SYNONYMS: PR-3500-19.	

new

7188

NOTE: Not intended for consumer use

II. HAZARDOUS INGREDIENTS

MATERIAL OR COMPONENT	CAS NO UN NO.	%	OSHA PEL	ACGIH TLV	HAZARD
DICHLOROMETHANE	75-09-2	50	500ppm	50ppm	VAPOR HAZARD; SUSPECTED CARCINOGEN BY ANIMAL STUDIES
PHENOL	108-95-2	20	5ppm	5ppm	CORROSIVE, POISON
SODIUM CHROMATE	07775-11-3	0.8	NONE	.5ppm	OXIDIZER, SUSPECTED CARCINOGEN

III. PHYSICAL DATA

BOILING POINT, 760 mm Hg: ABOVE 115°F	MELTING POINT: N/A
SPECIFIC GRAVITY (H_2O=1): 1.2	VAPOR PRESSURE: 200 mm
VAPOR DENSITY (AIR=1): 2.9	SOLUBILITY IN H_2O, % BY WT.: PARTIALLY SOLUBLE
% VOLATILES BY VOL.: 80%	EVAPORATION RATE (WATER =1): 1
APPEARANCE AND ODOR: THICK YELLOW LIQUID PHENOL ODOR	pH (AS IS): 9 / pH AT N/A DILUTION

IV. FIRE AND EXPLOSION DATA

FLASH POINT (TEST METHOD): NONE	AUTO IGNITION TEMPERATURE: ABOVE 1000°F	FLAMMABLE LIMITS IN AIR, % BY VOL.: LOWER: NONE UPPER: NONE

EXTINGUISHING MEDIA: N/A

SPECIAL FIRE FIGHTING PROCEDURES: SELF CONTAINED BREATHING APPARATUS REQUIRED

UNUSUAL FIRE AND EXPLOSION HAZARD: CAUSES TOXIC CHLORIDE FUME ON CONTACT WITH OPEN FLAME.

HEALTH HAZARD INFORMATION

HEALTH HAZARD DATA	HAZARD	EFFECTS OF OVEREXPOSURE
ROUTES OF EXPOSURE		
INHALATION		
Acute:	HIGH, ABSORBED IN LUNGS	NARCOSIS, NAUSEA, DIZZINESS
Chronic:	SLIGHT	SUSPECTED CARCINOGEN BY ANIMAL STUDIES
SKIN CONTACT		
Acute:	HIGH, CORROSIVE TO SKIN	CORROSIVE TO SKIN
Chronic:	SLIGHT, IRRITATING TO SKIN	DEFATS AND IRRITATES SKIN
SKIN ABSORPTION		
Acute:	LOW, TOO IRRITATING FOR SKIN	ABSORPTION: NONE
Chronic:	NONE	NONE
EYE CONTACT		
Acute:	HIGH, CORROSIVE TO EYES	CAUSES BLURRY VISION FOR SEVERAL WEEKS
Chronic:	NONE	NONE

EMERGENCY AND FIRST AID PROCEDURES

EYES FLUSH WITH WATER FOR 15 MINUTES SEEK MEDICAL ATTENTION

SKIN FLUSH WITH WATER, WASH WITH SOAP AND WATER

INHALATION REMOVE TO FRESH AIR

VI. REACTIVITY DATA

INCOMPATIBILITY (MATERIALS TO AVOID)

STRONG ALKALIS, STRONG ACIDS, STRONG OXIDIZERS

HAZARDOUS DECOMPOSITION PRODUCTS

HEAT WILL PRODUCE DICHLOROMETHANE AND AMMONIA FUMES

VII. SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IF MATERIAL IS RELEASED OR SPILLED ALLOW TO EVAPORATE, SWEEP UP RESIDUE WITH ABSORBENT RINSE WITH WATER

DISPOSAL METHODS USEPA HAZARDOUS WASTE NO.S U080, D007, U188

CONSULT FEDERAL, STATE AND LOCAL REGULATORY AGENCIES FOR PROPER DISPOSAL.

VIII. CONTROL MEASURES

VENTILATION REQUIREMENTS	MATERIAL TRANSFER OR SPILL	MATERIAL USE
VENTILATION	100 FT/MIN	100 FT/MIN
RESPIRATORY	SCBA REQUIRED IF LIMITS EXCEEDED	SCBA REQUIRED IF LIMITS EXCEEDED
EYE PROTECTED EQUIPMENT	FACE SHIELD AND GOGGLES	FACE SHIELD AND GOGGLES
GLOVES	POLYETHYLENE	POLYETHYLENE
OTHER EQUIPMENT	RUBBER APRON AND BOOTS	RUBBER APRON AND BOOTS
WORK PRACTICES	DO NOT USE IN CONFINED SPACE. AVOID ALL SKIN CONTACT	DO NOT USE IN CONFINED SPACE. AVOID ALL SKIN CONTACT

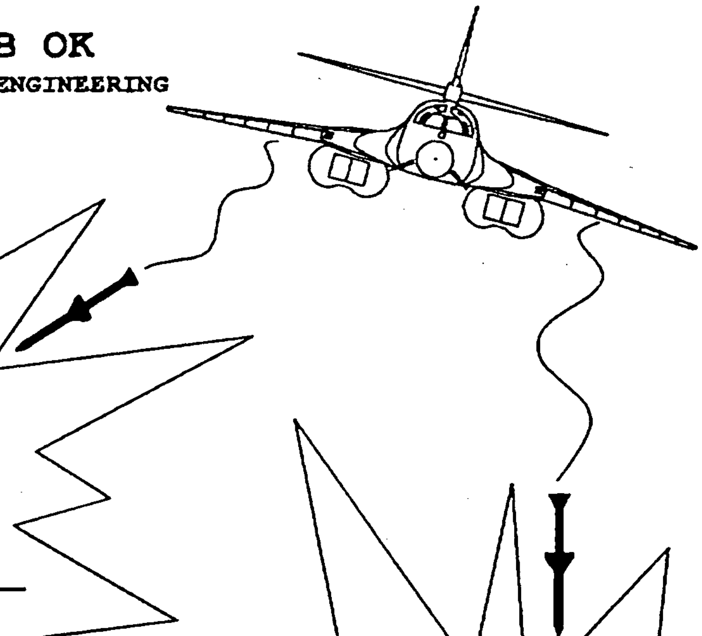
PREPARED BY: Pat E. Smith DATE PREPARED 6/13/89

SIGNATURE Pat E. Smith

TOTAL P.03

TINKER AFB OK

AIRCRAFT PRODUCTION ENGINEERING



FROM THE DESK OF
GEORGE W. BAXTER
OC-ALC/LAPEP
PH: (405) 736-5986
FAX: 736-4178
DATE: 25 Oct 96

TO: Shyam Venkatesh
ORGANIZATION:
Acurex Environmental
PH: (415) 254-2486
FAX: (415) 254-2497
SUBJECT: PR 5000/3140 MSDS's
PAGES (W/COVER): 5

Do not transmit classified information Over unsecured telecommunications systems. Official DOD telecommunications systems are subject to monitoring. Use of DOD telecommunications systems constitutes consent to monitoring.

ELDORADO PR-3140, PAINT REMOVER

1
2 0
NONE

MATERIAL SAFETY DATA SHEET

I. PRODUCT IDENTIFICATION

MANUFACTURER'S NAME: ELDORADO CHEMICAL COMPANY, INC.	REGULAR TELEPHONE 210-653-9323 FAX NO. 210-653-0825 EMERGENCY (CHEM-TEL, INC.) TELE NO 1-800-255-3924
ADDRESS: P.O. BOX 34837, SAN ANTONIO, TEXAS 78265	
CHEMICAL NAME OR FAMILY: N/A	SHIPPING NAME (DOT): NOT REGULATED
TRADE NAME AND SYNONYMS: PR-3140	

NOTE: Not intended for consumer use

II. HAZARDOUS INGREDIENTS

MATERIAL OR COMPONENT	CAS NO UN NO.	%	OSHA PEL	ACGIH TLV	HAZARD
AMMONIA	7664-41-7	<5	NONE	25ppm	VAPOR HAZARD; CORROSIVE

III. PHYSICAL DATA

BOILING POINT, 760 mm Hg	ABOVE 300°F	MELTING POINT	-10°F
SPECIFIC GRAVITY (H_2O=1)	1.0	VAPOR PRESSURE	1mm @ 24°C
VAPOR DENSITY (AIR=1)	2	SOLUBILITY IN H_2O, % BY WT.	SOLUBLE
% VOLATILES BY VOL.	95%	EVAPORATION RATE (WATER =1)	LESS THAN 1
APPEARANCE AND ODOR	THICK, LIQUID; AMMONIA ODOR	pH (AS IS) 12 pH AT DILUTION	N/A

IV. FIRE AND EXPLOSION DATA

FLASH POINT (TEST METHOD) ABOVE 200°F	AUTO IGNITION TEMPERATURE ABOVE 400°F	FLAMMABLE LIMITS IN AIR, % BY VOL.	LOWER: 2% UPPER: 15%
EXTINGUISHING MEDIA	WATER, FOAM, DRY POWDER		
SPECIAL FIRE FIGHTING PROCEDURES	CARBON FILTERS REQUIRED TO AVOID BREATHING OF VAPORS.		
UNUSUAL FIRE AND EXPLOSION HAZARD	TOXIC VAPORS MAY BE EMITTED.		

PRODUCT PR-3140

V. HEALTH HAZARD INFORMATION

HEALTH HAZARD DATA		HAZARD	EFFECTS OF OVEREXPOSURE
ROUTES OF EXPOSURE			
INHALATION	Acute:	SLIGHT; LOW VAPOR PRESSURE	IRRITATING TO LUNGS
	Chronic:	MODERATE; LOW VAPOR PRESSURE	ABSORBED IN LUNGS
SKIN CONTACT	Acute:	MODERATE; ABSORBED BY SKIN	DEFATS AND IRRITATES SKIN
	Chronic:	MODERATE; ABSORBED BY SKIN	DEFATS AND IRRITATES SKIN
SKIN ABSORPTION	Acute:	LOW	SKIN ABSORPTION IS SLOW UNDER USE CONDITIONS
	Chronic:	LOW	MAY CAUSE SYSTEMIC DAMAGE
EYE CONTACT	Acute:	MODERATE	IRRITATION; MAY BE CORROSIVE TO EYES
	Chronic:	NONE; PAIN PREVENTS REPEATED EXPOSURE	NONE EXPECTED UNDER USE CONDITIONS

EMERGENCY AND FIRST AID PROCEDURES

EYES: FLUSH WITH WATER FOR 15 MINUTES; CONSULT PHYSICIAN.

SKIN: WASH WITH SOAP AND WATER.

INHALATION: REMOVE TO FRESH AIR.

INGESTION: DRINK VOLUMES OF WATER; CONTACT PHYSICIAN IMMEDIATELY.

VI. REACTIVITY DATA

INCOMPATIBILITY (MATERIALS TO AVOID)
OXIDIZERS, REACTIVE METALS

HAZARDOUS DECOMPOSITION PRODUCTS
COMBUSTION MAY PRODUCE TOXIC GASES (NITROGEN OXIDES, ETC.)

VII. SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IF MATERIAL IS RELEASED OR SPILLED SCOOP LARGE SPILLS INTO DRUMS; SMALL SPILLS MAY BE PICKED UP WITH ABSORBENT.

DISPOSAL METHODS USEPA HAZARDOUS WASTE NO.'S AS IS: PRODUCT IS NOT CONSIDERED TO BE A HAZARDOUS WASTE BY EPA GUIDELINES.

CONSULT FEDERAL, STATE AND LOCAL REGULATORY AGENCIES FOR PROPER DISPOSAL.

VIII. CONTROL MEASURES

SAFETY REQUIREMENTS	MATERIAL TRANSFER OR SPILL	MATERIAL USE
VENTILATION	50 FT/MIN	50 FT/MIN
RESPIRATORY	SCBA REQUIRED IF LIMITS EXCEEDED	SCBA REQUIRED IF LIMITS EXCEEDED
EYE PROTECTED EQUIPMENT	FACE SHIELD AND GOGGLES	FACE SHIELD
GLOVES	RUBBER OR NEOPRENE	RUBBER
OTHER EQUIPMENT	APRONS AND BOOTS	APRONS AND BOOTS
WORK PRACTICES	AVOID PROLONGED SKIN CONTACT	AVOID PROLONGED SKIN CONTACT

PREPARED BY: BOB E. FLYNT DATE PREPARED 9/13/95

SIGNATURE

ELDORADO PR 5000, PAINT REMOVER*

0 3 1 CORR

MATERIAL SAFETY DATA SHEET

I. PRODUCT IDENTIFICATION

MANUFACTURER'S NAME	ELDORADO CHEMICAL COMPANY, INC.
REGULAR TELEPHONE	210-653-9323
FAX NO.	210-653-0825
EMERGENCY (CHEM TEL, INC.) TELE. NO.	1 800-255-3924
ADDRESS	P.O. BOX 34837, SAN ANTONIO, TEXAS 78265
CHEMICAL NAME OR FAMILY	N/A
SHIPPING NAME (DOT):	CORROSIVE LIQUID, N.O.S. (INORGANIC PEROXIDES), 8, UN-1760, II.
TRADE NAME AND SYNONYMS	ELDORADO PR-5000, PAINT REMOVER

NOTE: Not intended for consumer use

II. HAZARDOUS INGREDIENTS

MATERIAL OR COMPONENT	CAS NO UN NO.	%	OSHA PEL	ACGIH TLV	HAZARD
THE MATERIALS USED IN THE MANUFACTURE OF THIS PRODUCT ARE NOT LISTED, OR ARE BELOW THE REPORTING REQUIREMENTS OF O.S.H.A. IN 29 CFR SUBPART Z.	N/A	N/A	N/A	N/A	N/A
ALSO CONTAINS:					
PEROXIDES NOT LISTED	N/A	20	N/A	N/A	CORROSIVE TO SKIN & EYES

DANGER! CORROSIVE TO SKIN AND EYES.

III. PHYSICAL DATA

BOILING POINT, 760 mm Hg	>180°F	MELTING POINT	>32°F
SPECIFIC GRAVITY (H_2O=1)	1.04	VAPOR PRESSURE	APPROX. 24
VAPOR DENSITY (AIR-1)	1	SOLUBILITY IN H_2O, % BY WT.	40%
% VOLATILES BY VOL	99%	EVAPORATION RATE (WATER =1)	1
APPEARANCE AND ODOR	THICK, CLEAR LIQUID; MILD ODOR	pH (AS IS)	5
		pH AT 1% DILUTION	6

IV. FIRE AND EXPLOSION DATA

FLASH POINT (TEST METHOD)	ABOVE 200°F T.C.C.	AUTO IGNITION TEMPERATURE	ABOVE 400°F
FLAMMABLE LIMITS IN AIR, % BY VOL.	LOWER: 5%	UPPER: 12%	

EXTINGUISHING MEDIA: WATER

SPECIAL FIRE FIGHTING PROCEDURES: USE SELF-CONTAINED BREATHING APPARATUS.

UNUSUAL FIRE AND EXPLOSION HAZARD: TOXIC NITROGEN OXIDES MAY BE FORMED.

PRODUCT.. PR-5000

V. HEALTH HAZARD INFORMATION

HEALTH HAZARD DATA		HAZARD	EFFECTS OF OVEREXPOSURE
ROUTES OF EXPOSURE			
INHALATION	Acute:	CORROSIVE	CAN CAUSE UPPER RESPIRATORY IRRITATION
	Chronic:	NONE	NONE EXPECTED
SKIN CONTACT	Acute:	CORROSIVE	CAUSES BURNS ON SHORT EXPOSURE
	Chronic.	SLIGHT	DERMATITIS CAN OCCUR
SKIN ABSORPTION	Acute:	SLIGHT	CAUSES BURNS
	Chronic:	SLIGHT	SKIN ABSORPTION MAY CAUSE SYSTEMIC DAMAGE
EYE CONTACT	Acute	CORROSIVE	BURNS EYES ON CONTACT
	Chronic:	SLIGHT	PAIN WILL PREVENT CHRONIC EXPOSURE

EMERGENCY AND FIRST AID PROCEDURES

EYES: FLUSH WITH WATER FOR 15 MINUTES; CONSULT PHYSICIAN.

SKIN. FLUSH WITH WATER FOR 15 MINUTES; WASH WITH SOAP AND WATER.

INHALATION: REMOVE TO FRESH AIR.

INGESTION: DRINK VOLUMES OF WATER; CONSULT PHYSICIAN.

VI. REACTIVITY DATA

INCOMPATIBILITY (MATERIALS TO AVOID)
REACTIVE METALS, ALKALIS, REDUCING AGENTS

HAZARDOUS DECOMPOSITION PRODUCTS
IN FIRE, MAY PRODUCE CARBON MONOXIDE, CARBON DIOXIDE, AND NITROGEN OXIDES.

VII. SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IF MATERIAL IS RELEASED OR SPILLED
CONTAIN AND CLEAN UP WITH ABSORBENT.

DISPOSAL METHODS USEPA HAZARDOUS WASTE NO.'S AS IS: PRODUCT IS NOT CONSIDERED A HAZARDOUS WASTE BY EPA GUIDELINES.
CONSULT FEDERAL, STATE AND LOCAL REGULATORY AGENCIES FOR PROPER DISPOSAL.

VIII. CONTROL MEASURES

SAFETY REQUIREMENTS	MATERIAL TRANSFER OR SPILL	MATERIAL USE
VENTILATION	100 FT/MIN	100 FT/MIN
RESPIRATORY	SCBA REQUIRED IF LIMITS EXCEEDED	SCBA REQUIRED IF LIMITS EXCEEDED
EYE PROTECTED EQUIPMENT	FACE SHIELD OR GOGGLES	FACE SHIELD OR GOGGLES
GLOVES	POLYETHYLENE	POLYETHYLENE
OTHER EQUIPMENT	FULL WASH RACK GEAR	FULL WASH RACK GEAR
WORK PRACTICES	RINSE EXTERIORS OF ALL CONTAINERS	AVOID ALL SKIN CONTACT; RINSE ALL SPILLS

PREPARED BY ROB E. FLYNT DATE PREPARED.. 4/29/96

SIGNATURE

OCT 25 '96 10:09 4057264170 PAGE.005

APPENDIX C

CONTROL SYSTEM COSTS: COST SPREADSHEETS AND VENDOR QUOTES

CARBON ADSORPTION DESIGN AND COST ESTIMATES				
Based on:				
OAQPS Control Cost Manual, 4th ed., EPA 450/3-90-006, William M. Vavatuk				
AIR STREAM INFORMATION				
1	Exhaust Air Flow Rate Q, scfm	450,000	225,000	
FIXED BED DESIGN				
	Carbon Requirement, C(req)			
	C(req) = M(HAP) *t(ad)/Wc			
	W(c)=Carbon Working Capacity			
	M(HAP) = HAP inlet loading lb/hr			
	t(ad) = time of adsorption, hr			
	If W(e) = equilibrium capacity			
	W(c) = 0.5*W(e)			
	Adsorption capacity of activated carbon (ref: AWMA paper 95-WA78A.02)			
	MC W(e) @100 ppmv, lb/lb	0.05	0.05	
	MC W(e) @ 1000 ppmv, lb/lb	0.12	0.12	
	Phenol W(e) @ 100 ppmv, lb/lb	0.45	0.45	
	Phenol W(e) @ 1000 ppmv, lb/lb	0.55	0.55	
	For design purposes assume			
	HAP concentration in ppmv as =	500	500	
6	MC concentration, ppmv	500	500	
	Phenol concentration, ppmv	0	0	
	W(c) for MC, lb/lb	0.041	0.041	
	W(c) for Phenol, lb/lb	0.219	0.219	
	Assume t(ad) , hr	4	4	
	M(HAP) MC, lb/hr	2970	1485	
	M(HAP) Phenol, lb/hr	0	0	
	M(HAP) Total, lb/hr	2970	1485	
	M(HAP) Total in t(ad), hr	11880	5940	
	C(req), lb	292932	146466	
7	Vessel Dimensions			
	Diameter D is given by:			
	D = (0.127)*C(req)*Vb/Q			
	Length L is given by:			
	L= (7.87/C(req))*(Q/Vb)^2			
	Assume superficial velocity Vb, fpm	85	85	
	Assume carbon bulk density d, lb/cu.ft	30	30	
	Vessel Diameter D, ft	7.0	7.0	
	Vessel length L, ft	753	377	
	Vessel Surface Area S, sq.ft	16693	8385	
CAPITAL COSTS				
	Carbon cost, C(c) = 2*C(req), $	585863	292932	
	Vessel cost, C(v) = 271*S^0.778*(1.05)^7, $	735220	430310	
	Adsorber Cost	1321084	723242	
9	Total Purchased Cost			
	Total adsorber equipment cost C(A)			
	C(A) = Rc*(C(c) + (N(A) + N(D))*C(v))			
	N(A) = number of adsorbing vessels			

CARBON ADSORPTION DESIGN AND COST ESTIMATES				
Based on:				
OAQPS Control Cost Manual, 4th ed., EPA 450/3-90-006, William M. Vavatuk				
AIR STREAM INFORMATION				
1	Exhaust Air Flow Rate Q, scfm	450,000	225,000	
	N(D) = Number of desorbing vessels			
	Rc = 5.82Q^-0.133			
	4,000 <= Q(acfm) <= 500,000			
	N(A)	1	1	
	N(D)	0	0	
	Rc	1.03	1.13	
	C(A), $	1356064	814255	
10	Direct Costs, $			
	Purchased Equipment Costs, PEC			
	C(A)	1356064	814255	
	Instrumentation	135606	81426	
	Sales Tax	40682	24428	
	Freight	40682	24428	
	PEC	1573034	944536	
	Direct Installation Costs, DIC			
	Foundation and Supports	125843	75563	
	Handling and Erection	220225	132235	
	Electrical	62921	37781	
	Piping	31461	18891	
	Insulation	15730	9445	
	Painting	15730	9445	
	DIC	471910	283361	
	Site Preparation, SP	23596	14168	
	Total Direct Costs TDC, $			
	TDC = PEC + DIC + SP	2068539	1242065	
11	Indirect Costs(installation & Startup)			
	Engineering	157303	94454	
	Construction and Field Expenses	78652	47227	
	Contractor Fees	157303	94454	
	Start-up	31461	18891	
	Performance Test	15730	9445	
	Contingencies	47191	28336	
	Total Indirect Costs TIDC, $	487640	292806	
12	Total Capital Investment, TCI = TDC + TIDC, $	2556180	1534871	
	$/cfm	**5.7**	**6.8**	
OPERATING COSTS				
	Steam			
	Steam Requirements for Desorbing:			
	Price of steam per 1,000 lb, $	8.0	8.0	
	Approximate amount of steam required to			
	desorb one lb of VOC, lb	3.5	3.5	
	Annual emissions of VOCs			
	Qty per A/C * No. of aircraft, lb	530000	530000	
	Yearly steam requirement for desorption, lb	1855000	1855000	
	Average desorption time, hr	8	8	
	Steam flowrate through adsorber, lb/hr	4216	4216	

CARBON ADSORPTION DESIGN AND COST ESTIMATES				
Based on:				
OAQPS Control Cost Manual, 4th ed., EPA 450/3-90-006, William M. Vavatuk				
AIR STREAM INFORMATION				
1	Exhaust Air Flow Rate Q, scfm	450,000	225,000	
13	Yearly cost of steam C(s), $	14840	14840	
	Cooling Water			
	Cooling Water Requirements for Condensor:			
	Amount of cooling water per lb of steam, lb	28.6	28.6	
	(del T of cooling water 35 F)			
	Price per 1,000 gal of cooling water, $	0.30	0.30	
	Price per 10,000 lb of cooling water, $	0.36	0.36	
14	Yearly cost of cooling water C(w), $	1911	1911	
	Electricity			
	Major electricity users			
	Main system ID fan, cooling water pumps			
	and bed drying/cooling fan			
	Assume carbon bed system			
	system pressure drop del P, in. of H2O	10	10	
	system fan usage t(s):			
	(55 ac/year* 4days per a/c* 24 hr/day), hr/yr	5280	5280	
	system fan power consumption:			
	hpsf = 2.5*Q*del P	11250000	5625000	
	kWhsf=hpsf*10^-4*t(s)*0.746, kWh/yr	4431240	2215620	
	Bed drying/cooling fan			
	0.1*kWhsf, kWh/yr	443124	221562	
	Cooling water pumps:			
	2.52*10^-4*Q(cw)*H*S/eta			
	Q(cw) = cooling water flowrate, gal/min	241	241	
	H = head in feet	100	100	
	S, is specific gravity w.r.t water	1	1	
	eta = pump + motor efficiency	0.63	0.63	
	cooling water power hpcw, hp	10	10	
	Assume drying cycle 2 days per a/c			
	55 a/c * 2 days pera/c* 24 hrs/day gives			
	Total cooling water requirements, hr/yr	2640	2640	
	Cooling water pump power usage, kWh/yr	19012	19012	
	Total Power Consumption:			
	System Fan+Drying Fan+CW Pump, kWh/yr	4893376	2456194	
15	Total Cost of Electricity @$0.07/kWh, $	342536	171934	
16	Total Utility Costs:			
	Steam + CW + Electricity, $	359288	188685	
	Carbon Replacement Costs (5 yr life)			
	C(RCc) = C(RFc)*(1.08*C(c) + C(lc))			
	C(RFc)= capital recovery factor of the carbon	0.2638	0.2638	
	1.08 = taxes and freight			
	C(c) = initial cost of carbon	585863	292932	
	C(lc) = carbon removal labor costs, $0.06/lb	17576	8788	
17	Carbon Replacement Costs C(RCc), $	171551	85776	
	Carbon Disposal Costs (As hazardous waste):			

CARBON ADSORPTION DESIGN AND COST ESTIMATES				
Based on:				
OAQPS Control Cost Manual, 4th ed., EPA 450/3-90-006, William M. Vavatuk				
AIR STREAM INFORMATION				
1	Exhaust Air Flow Rate Q, scfm	450,000	225,000	
	Assume present cost for disposal, $1/lb			
	Total cost of disposal in 5 years, $	373863	186932	
18	Annualized cost of disposal per year	74773	37386	
19	Recovery Credits	0	0	
	Annual Operating Costs per Unit, $	530839	274461	
	Number of Units	1	3	
21	Total Annual Operating Costs, $	530839	823382	
22	**Annual Operating Cost per acfm, $/acfm**	**1.2**	**1.2**	
*** The estimated annual operating cost, and capital investment cost are lower than**				
those typically quoted by vendors. The average CI for greater than 200,000 cfm used				
is $10/cfm. The average AOC is $1.6/cfm				

	REGENERATIVE THERMAL OXIDATION - DESIGN AND COST ESTIMATES						
	Based on:						
	OAQPS Control Cost Manual, 4th ed., EPA 450/3-90-006, William M. Vavatuk						
1	Exhaust Air Flowrate, acfm	450,000	45,000	25,000			
2	Annualized amount of MC used per A/C, lb	5300	5300	5300			
3	MC emission duration	30	8	8			
3	Average MC emission rate, lb/hr	177	663	663			
4	Average MC concentration, ppmv	30	1112	2002			
5	MC flowrate, acfm	13	50	50			
	REGENERATIVE THERMAL OXIDIZER DESIGN DATA						
5	Oxidizer operating temperature, °F	1600	1600	1600			
	°C	871	871	871			
6	MC heat of combustion, Btu/scf	705	705	705			
	Mixture (air+MC) heat of comb., Btu/scf	0.02	0.78	1.41			
	Waste gas density (assume air), lb/ft3	0.0739	0.0739	0.0739			
	Waste gas heating value, Btu/lb	0.3	10.6	19.1			
7	Reference temperature T(ref), °F	77	77	77			
	°C	25	25	25			
8	Regeneration Efficiency, %	95	95	95			
	Pre-heater exit gas temperature, °F	1520	1520	1520			
9	Total oxidizer system energy losses, %	15	15	15			
	Residence time, seconds	0.75	0.75	0.75			
	Assume Auxiliary Fuel is Natural Gas						
	Densities, lb/ft3						
	auxiliary fuel	0.0408	0.0408	0.0408			
	waste gas in	0.0739	0.0739	0.0739			
	waste gas out	0.0739	0.0739	0.0739			
	Temperatures, °F						
	Reference = auxiliary fuel in	77	77	77			
	Oxidizer temperature	1600	1600	1600			
	preheat temperature	1520	1520	1520			
	specific heat - waste gas (air), Btu/lb/°F	0.255	0.255	0.255			
	Waste gas flowrate, acfm	450,013	45,050	25,050			
	Waste gas heat of combustion, Btu/lb	0.3	10.6	19.1			
	Auxiliary fuel heating value, Btu/lb	21502	21503	21504			
10	Auxiliary Fuel Flowrate, acfm	125.2	10.9	5.3			
	(By energy balance around combustor)						
	FLUE GAS SCRUBBER DATA						
	MC emissions, lb/hr	177	663	663			
	HCl emissions, lb/hr	152	569	569			
	Approximate HCl partial pressure	0.00	0.14	0.25			
11	HCl solubility @ above PP, kg/m3	350	450	450			

	(Absorption Towers, Morris and Jackson, TP146.A3)						
	Theoretical water needed to scrub, lb/hr	434	1264	1264			
	gal/hr	52	152	152			
12	Taking into account absorption						
	efficiencies etc. (actual = 1.5*theor.), gal/hr	78	228	228			
	COST ANALYSIS						
	TOTAL CAPITAL INVESTMENT						
	Equipment Costs (EC)						
13	Thermal Oxidizer						
	EC=(2.204x10^5 +11.57*Q(tot))*(1.05)^7, $	7307139	1010584	699614.8			
	HCl Absorber Cost						
14	Assume 30" column diameter, $	17589	17589	17589			
	(Re: Control Technologies for HAPs, HAndbook - pp. 4-50, EPA/625/6-91/014)						
15	Total Equipment Cost (TEC), $	7324728	1028173	717203.5			
	Direct Costs, $						
	TEC	7324728	1028173	717204			
	Instrumentation, 0.1*TEC	732473	102817	71720			
	Sales Taxes 0.03*TEC	21974	3085	2152			
	Freight, 0.05*TEC	366236	51409	35860			
16	Purchased Equipment Cost, PEC	8445411	1185483	826936			
	Direct Installation Costs (DIC), $						
	Construction/Erection, 0.22*PEC	1857991	260806	181926			
	Electrical, 0.04*PEC	337816	47419	33077			
	Piping, Ductwork, Insulation, etc., 0.0.03*PEC	253362	35564	24808			
	Painting, 0.01*PEC	84454	11855	8269			
17	Direct Installation Costs- 0.3*PEC, DIC	2533623	355645	248081			
	Indirect Costs (Installation), $						
	Engineering, 0.01*PEC	844541	118548	82694			
	Construction and Field Expenses, 0.05*PEC	422271	59274	41347			
	Contractor fees, 0.1*PEC	844541	118548	82694			
	Start-up, 0.02*PEC	168908	23710	16539			
	Performance Test, 0.01*PEC	84454	11855	8269			
	Contingencies, 0.03*PEC	253362	35564	24808			
18	Total Indirect Installation Costs (TIIC), 0.31*PEC	2618078	367500	256350			
19	Total Capital Investment (PEC+DIC+TIIC), $	13597113	1908628	1331366			
	OPERATING COSTS						
	Auxiliary Fuel Usage, cfh	7513	654	319			
	Price per 1000 cft of natural gas, $	4.64	4.64	4.64			
	Annual oxidizer usage, hr	5808	5808	5808			
	55 ac per yr * 4 days/ac * 24 hrs + 10% of						
	total time for start-up						
	Annual natural gas usage, cfh	43636550	3800217	1853960			
20	Annual Cost of Natural Gas, $	202623	17646	8609			

	Absorber water usage, gal/h	78	228	228			
	Yearly water usage (absorber, quench, etc.), gal	453544.4	1322838	1322838			
21	Cost of water @ $0.3/1000 gal, $	136	397	397			
22	Yearly caustic usage for pH maintenance and						
	scrubbing chlorine, lb	401241	401241	401241			
	Cost at $0.35/lb	140434	140434	140434			
	Electricity						
	Main Fan, Induced Draft (ID)						
	Q(tot)= total flow through system, cfm	450,139	45,061	25,055			
	del P = system pressure drop, in WC	25	25	25			
	feff = overall fan efficiency	0.63	0.63	0.63			
	Fan Power = 1.17^10-4*Q(tot)*delP/feff, kW	2090	209	116			
	Annual ID-fan power consumption, kWh	12138308	1215101	675636.2			
	Cost of electricity per kWh, $	0.08	0.08	0.08			
	Annual cost of ID-fan operation, $	971065	97208	54051			
	Water usage:						
	Liquor pump power (use 10 HP pump), kW	7.5	7.5	7.5			
	Annual power usage by liquor pump, kWh	43328	43328	43328			
23	Annual cost of power for liquor pump, $	3466	3466	3466			
	Total Annual Electricity Costs for						
	Oxidizer Operation:						
24	(I.D. Fan + Liquor Pump +10% Other), $	1071984	110742	63269			
25	Scrubber liquor disposal cost:						
	(assume none -- non-hazarous), $	0	0	0			
26	Annual Operating Costs, $	1415178	269219	212709			
27	Total Capital Investment, $	13597113	1908628	1331366			
	AOC, $/cfm	**3.1**	**6.0**	**8.5**			
	CI, $/cfm	**30**	**42**	**53**			
Based on discussions with vendors and other lietrature, the average cost							
for 450,000 cfm was used in the report as CI = $25/cfm and AOC = $6/cfm							
for 50,000 cfm was used in the report as CI = $40/cfm and AOC = $8/cfm							

VARA INTERNATIONAL
Division of Calgon Carbon Corporation
1201 19th Place, Vero Beach, FL 32960
Telephone: 561-567-1320
Telefax: 561-567-4108

FACSIMILE MESSAGE

IF YOU DO NOT RECEIVE ALL THE PAGES, PLEASE CALL US BACK AS SOON AS POSSIBLE. VARA INTERNATIONAL (561) 567- 1320.

PLEASE DELIVER THE FOLLOWING PAGES TO:

NAME: Mr. Shyam Venkatesh

LOCATION: Acurex Environmental

FROM: Dennis A. Lobmeyer

LOCATION: VARA INTERNATIONAL
DIVISION OF CALGON CARBON CORPORATION
FAX (561) 567-4108

DATE: October 21, 1996

TOTAL NUMBER OF PAGES: 6 **(INCLUDING COVER PAGE).**

COMMENTS:

VARA INTERNATIONAL
Division of Calgon Carbon Corporation

CALGON
CALGON CARBON CORPORATION

1201 19th Place
Vero Beach, Florida 32960
Telephone 561-567-1320
Telefax 561-567-4108

October 21, 1996

Acurex Environmental
555 Clyde Avenue
Mountain View, CA 94039

Attention: Mr. Shyam Venkatesh

Reference: VARA Preliminary Budget Proposal No. P. 2847

Dear Mr. Venkatesh:

In follow-up to our visit and subsequent conversations that you have had with Mr. Malcolm Hartle of Neu Engineering, we are pleased to submit this Preliminary Budget Proposal for the design and supply of a VARA Activated Carbon Adsorption and Distillation System. Described below are preliminary design parameters and budgetary pricing for VARA's proposed solvent recovery system.

1.0 DESIGN BASIS:

1.1	SLA Flow (SCFM):	150,000
1.2	SLA Temperature (^{o}F):	90
1.3	SLA Relative Humidity (%):	50%
1.4	Solvent Load (Lb/Hr)	1,000
1.5	Expected Removal Efficiency:	95+%
1.6	System Type:	Steam Regenerable

2.0 PROCESS DESCRIPTION (Adsorption):

The solvent recovery process consists of adsorption of the solvents by activated carbon in the fixed bed adsorbers, followed by periodic regeneration of the carbon with low pressure steam and cooling/condensation of the reclaimed steam/solvent mixture. The SLA flows through all but one of specially designed, fixed bed carbon adsorbers where the solvents are removed and the clean air is discharged.

Periodically, based on a predetermined adsorption cycle (or a signal from an optional solvent "breakthru" analyzer), the air flow is automatically diverted from one adsorber to another and the spent carbon adsorber is regenerated.

The regeneration is accomplished by heating the carbon with saturated steam. As the bed heats up, the solvents are stripped from the carbon and the steam/solvent mixture flows into a shell and tube condenser where the vapors are cooled by indirect heat exchange with cooling water.

The condensed steam/solvent mixture flows into a decanter/receiver tank where the solvent can be physically separated from the water layer.

3.0 EQUIPMENT DESCRIPTIONS:

As currently envisioned, the system (equipment/engineering package) will consist of the following major components:

3.1 Adsorbers:

Quantity:	Five (5)
Size:	12'-0" Ø x 28'-0" WxW
Materials of Construction:	316 S.S. with titanium carbon support screens
Carbon Weight (Lbs/Adsorber):	30,000
Carbon Type:	Pelleted Coal Base

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CALGON CARBON CORPORATION

3.2 **Major Process Equipment Included in Budget Price:**

SLA blower, process condenser, decanter, distillation columns, tanks, field instruments, PLC based control panel with operator interface and an optional analyzer panel. The pumps, wet end and distillation systems will be skid-mounted to the maximum extent possible, with skid-mounted heat exchangers process/utility piping.

4.0 ESTIMATED DAILY UTILITY REQUIREMENTS:

Note: All Utilities based upon 24 Hours/Day of Operation

Electrical:

480v, 3∅, 60 Hertz

Demand: (kW)	575
Consumption: (kW-H/Day)	6,400

Steam:

(30 PSIG saturated)

Demand Rate: (Lbs/Hr)	7,400 (during regeneration only)
Consumption: (Lbs/Day)	16,320

Cooling Water:

Demand (gpm) - Adsorption: 80°F Supply, 30°F rise	575 (during regeneration only)

Chilled Water:

Demand (gpm) - Adsorption 40°F Supply, 10°F Rise	110 (during regeneration only)

5.0 APPROXIMATE LAYOUT/FOOT PRINT/WEIGHTS:

42' Width x 98' Length x 15' High

6.0 PRICING:

Preliminary budget pricing for the Carbon Adsorption System as described above, is, F.O.B. Fabrication Points:.. **$2,500,000 U.S. Dollars**

The above price does not include freight, taxes, duties or installation.

7.0 DELIVERY:

Deliveries can be tailored to meet the clients requirements.

8.0 WARRANTY:

Vara International warrants that the equipment sold hereunder shall be free from defects in materials and workmanship for a period of eighteen (18) months from date of shipment or one year from the date of start-up, whichever occurs first. This warranty excludes removal, reinstallation, and freight and does not apply to problems associated with normal wear and tear, improper maintenance, negligence, misuse, abuse, or the failure to operate the equipment in strict accordance with the operating and maintenance plan provided. All other warranties, either express or implied, are hereby disclaimed including, but not limited to, the warranty of merchantability and fitness for a particular purpose.

The system as supplied by VARA, has been specifically designed to handle the design basis furnished by the customer. Any changes, modifications or additions to this design basis or electronic program modifications to the VARA supplied control system, without written VARA approval, will result in a void of warranties and process guarantees.

VARA INTERNATIONAL
Division of Calgon Carbon Corporation

CALGON
CALGON CARBON CORPORATION

9.0 LIMITATION OF LIABILITY:

The Supplier's liability and the purchaser's exclusive remedy for any cause of action arising out of this transaction, including but not limited to breach of warranty, negligence and/or indemnification, is expressly limited to a maximum of the purchase price of the equipment sold hereunder. All claims of whatsoever nature shall be deemed waived unless made in writing within forty-five (45) days of the occurrence giving rise to the claim. In no event in writing within forty-five (45) days of the occurrence giving rise to the claim. In no event shall the Supplier for any reason or pursuant to any provision of the Warranty be liable for incidental or consequential damages, or damages in excess of the purchase price of the equipment supplied, nor shall the Supplier be liable of profits or fines by Governmental agencies.

10.0 INDEMNIFICATION:

Each party, until the expiration of the warranty period, will indemnify and save the other party harmless at all times against any liability on account of any and all claims, damages, law suits, litigation, expenses, counsel fees, and compensation arising out of property damages or injuries (including death) except to the extent caused by the negligence of the other party.

If you should have any questions, or require additional information, do not hesitate to contact us at your convenience.

Sincerely,

VARA INTERNATIONAL
Division of Calgon Carbon Corporation

Dennis A. Lobmeyer

Dennis A. Lobmeyer
Applications Engineer

DAL/sal
I/pro-oct96/2847acrx

faxcover.tfm

Regenerative Vapor Recovery Systems

FENIX SYSTEMS, LTD.

Fax Cover Sheet

Date: 09/20/96

To: SHYAM VENKATESH Phone: ( )

Fax: (415) 254-2497

Company: ACUREX ENVIRONMENTAL CORP

8 PAGES TOTAL

From: ROD PRODONOVICH Phone: (330) 637-7033

Fax: ( )

Company: FENIX SYSTEMS, LTD

Regarding: COST + INFO FOR PROJECT DISCUSSED. IF YOU HAVE ANY QUESTIONS, PLEASE CALL.

THANKS

Rod

Regenerative Vapor Recovery Systems

FENIX SYSTEMS, LTD.
31500 W 13 Mile Rd., Suite 220
Farmington Hills, MI 48334

ROD PRODONOVICH
Manager of Business Development

(800) 676-0183
(810) 855-1090
FAX (810) 855-1096

Regenerative
Vapor
Recovery
Systems

FENIX
SYSTEMS, Ltd.

September 20, 1996

Mr. Shyam Venkatesh
Acurex Environmental Corporation
555 Clyde Avenue
P.O. Box 7044
Mountain View, CA 94039

RE: Methylene Chloride Abatement Project for U.S. Air Force Depainting Operations

Dear Shyam:

Thank you for expressing an interest in Fenix Systems, Ltd., and our Regenerative Vapor Recovery Systems (RVRS). This letter and proposal are in reference to our recent conversations, regarding a possible application that your company may have for the RVRS technology.

It is our understanding that Acurex is compiling information for possible treatment technologies to be used for control, abatement, and recovery of volatile organic compounds (VOCs) produced from airplane depainting operations for the U.S. Air Force. This air stream contains methylene chloride, and this compound is being discharged at a flow rate of 50,000 standard cubic feet per minute (scfm).

Based upon the preliminary information that we have received, this project appears to be beyond the standard capacity of the RVRS technology. The VOC levels in the air stream, and the flow rates, are both above the normal operating limits of the RVRS.

However, Fenix is very interested in pursuing this project. We can perform an on-site pilot study to demonstrate the effectiveness of the RVRS technology, and a pilot-scale evaluation would probably be prudent prior to your client selecting a full-scale treatment technology.

I will be contacting you shortly to discuss this project in further detail. In the meantime, if you have any questions, or require additional information, please do not hesitate to contact me at (800)-676-0183. I am looking forward to working with you on this project.

Sincerely,
Fenix Systems, Ltd.

Rod Prodonovich
Manager of Business Development

enclosures

31500 W. 13 Mile Rd., Suite 220 • Farmington Hills, MI 48334
(800) 676-0183 • (810) 855-1090 • FAX: (810) 855-1096

FENIX SYSTEMS, LTD.

MODEL MAG 10000 (5)

PRELIMINARY PROPOSAL AND COST ESTIMATE

Project Data

Date: September 20, 1996

Contact: Mr. Shyam Venkatesh

Site Name: U.S. Air Force M.C. Abatement Project

Fenix Proposal: FNXPRP.146

Company: Acurex Environmental

Site Location: Unknown

Process Description: Methylene Chloride is used in a U.S. Air Force airplane depainting operation, producing emissions of volatile organic compounds (VOCs) and hazardous air pollutants (HAPs).

Contaminants (VOCs & Inorganics)	Influent Concentration	VOC Levels (lbs/hour)	Effluent Requirements	Air Flow Rate (acfm)
Methylene Chloride	350-2,000 ppm	248-2,250	> 95% DRE	50,000 scfm

Other Operational Parameters:

1) Moisture levels are the relative humidity of the air.

2) Process is intermittent (4-6 hours on, 8-10 hours off).

3) Desired removal efficiency (DRE) of HAPs is 95% or greater.

4) At an air flow rate of 50,000 standard cubic feet per minute (scfm), five RVRS MAG 10000 systems would be required (each capable of accommodating 10,000 scfm).

5) Influent VOC levels for this project are extremely high. Each MAG 10000 can treat approximately 50 pounds of methylene chloride per hour, while maintaining continuous operation. Slightly higher capacities might be achieved due to the intermittent operation of the depainting process. However, it is likely that the maximum VOC control capacity would be approximately 250 pounds/hour.

FENIX SYSTEMS, LTD.

REGENERATIVE VAPOR RECOVERY SYSTEM (RVRS)

<u>COST ESTIMATE FOR MODEL: MAG 10000 (5)</u>

<u>RVRS Model MAG 10000</u>:
Base Price .... $ 350,000.00 each
(this price does not include explosion-proof requirements,
a fan to provide air flow, or product holding tank)

Required Options/Modifications:

Five Systems Required $1,750,000.00

<u>Delivery</u>:
FOB Factory to Project Site .... $ 25-50,000.00
(includes crane rental for loading and unloading)

<u>System Installation:</u>
Labor & Materials .... $ 50-100,000.00
(price depends upon site-specific conditions and requirements)

<u>System Start-Up</u>:
One Week .... $ 10-20,000.00

Total Cost Of Project $1,835,000-1,920,000.00

<u>System Operation & Maintenance</u>: .... $ 5-10,000.00/month
(includes weekly system inspection and sampling,
not analytical costs)

<u>Estimated Annual Operational Costs:</u> .... $ 41,300-374,150.00/year*
(includes electricity requirements, nitrogen consumption,
and replacement of media lost through attrition)

*Note: Estimated annual operational costs do not include costs for disposal of VOCs, if they cannot be recycled.

FENIX SYSTEMS, LTD.
REGENERATIVE VAPOR RECOVERY SYSTEM (RVRS)

OPERATIONAL COST/BENEFIT ANALYSIS
(BASED UPON RECYCLING OF RECOVERED VOCS)

Project: Acurex M.C. Abatement for U.S. Air Force

Location: Unknown

RVRS Model: MAG 10000 (5 systems)

Fenix Proposal #: FNXPRP.146

Project Data

Compound	Influent VOC Loading Rate (pounds/hour)	VOC Recovery Rate (lbs/hour, @ 95% removal efficiency)	Estimated Recycle Value ($/pound)	Recycle Revenue ($/hour)	Operational Costs of RVRS ($/hour)	Payback ($/hour, recycle revenue - operational costs)
#1 Methylene Chloride	248 lbs/hour	236 lbs/hour	$0.20/lb	$47.20/hr	$16.52/hour	$30.68/hr
#2 Methylene Chloride	2,250 lbs/hour	2,138 lbs/hour	$0.20/lb	$427.60/hr	$149.66/hour	$277.94/hr

RVRS Operating Costs: The estimated operating costs of the RVRS are calculated by adding up all the electrical requirements, the nitrogen requirements, and the amount of "make-up" media that will need to added to the system. The electricity requirements of the RVRS are based upon: 1) the influent VOC loading rate or concentration, 2) the boiling point of each compound (@ -20" Hg), and 3) the heat of vaporization for each compound (BTU/pound). The estimated operating costs are based upon the present VOC loading rates, operating costs will decrease if VOC loading rates decrease. This is due to the fact that the majority of the operating costs can be attributed to the electrical consumption during each regeneration cycle, and the frequency of the regeneration cycles are based upon the influent VOC loading rate. The standard costs/unit used for this calculation are: Electricity = $0.10/KWH, Nitrogen = $0.02/scf, and Adsorbent = $0.066/gram

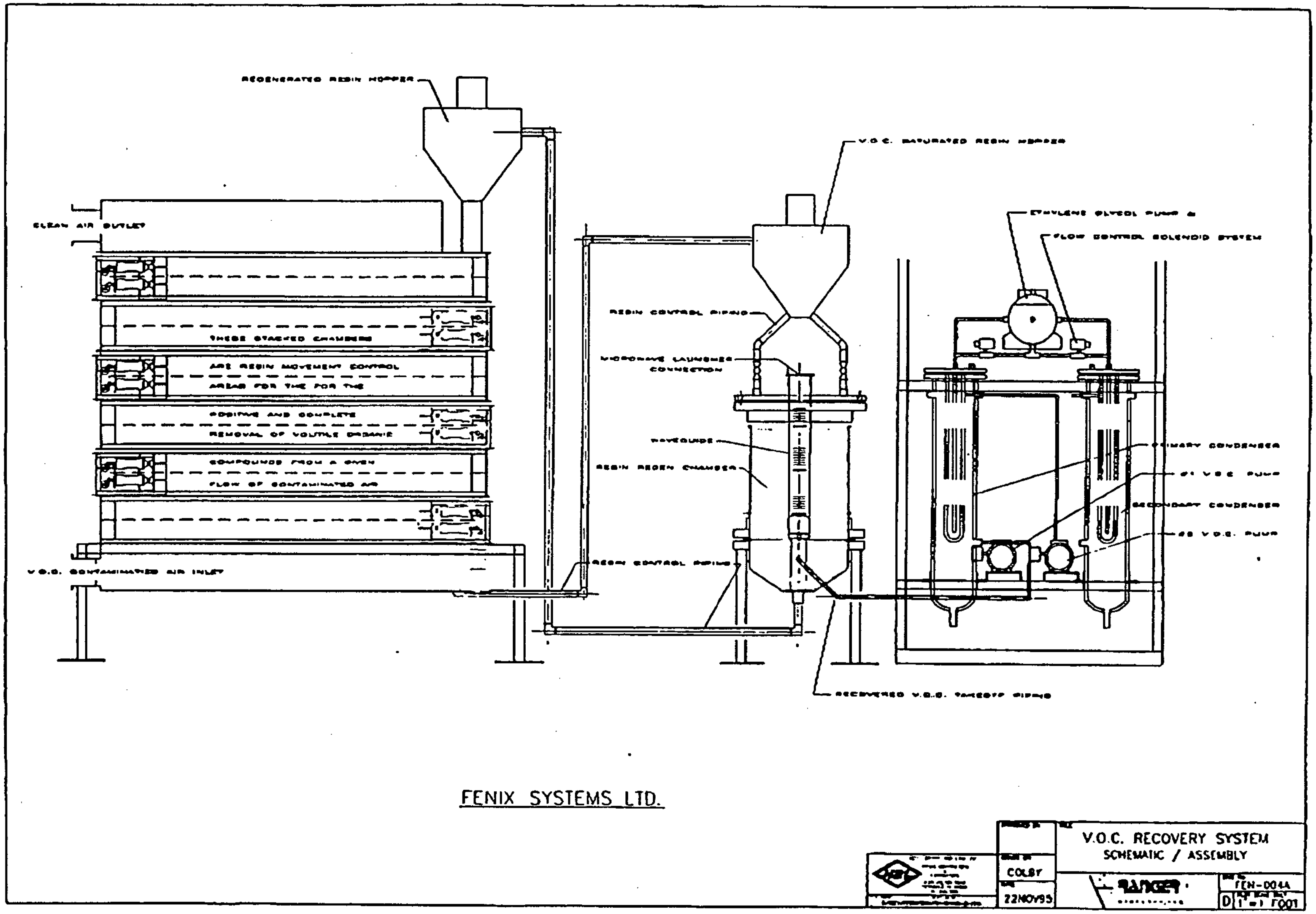
Scenario #1:

Total Estimated Operating Costs = $0.07/pound of VOC captured, or $16.52/hour
Total Estimated Recycle Revenue $118,000.00/year - $41,300.00 Total Estimated Annual Operating Costs/year
= Total Estimated Payback $76,700.00/year (based on 2,500 hours of operation/year).

Scenario #2:

Total Estimated Operating Costs = $0.07/pound of VOC captured, or $149.66/hour
Total Estimated Recycle Revenue $1,069,000.00/year - $374,150.00 Total Estimated Annual Operating Costs/year
= Total Estimated Payback $694,850.00/year (based on 2,500 hours of operation/year).

Note: Any solvent processing costs prior, to recycling, are not included in this analysis. Solvent recycle value based upon 50% of virgin solvent value.


REGENERATED RESIN HOPPER
CLEAN AIR OUTLET
THESE STACKED CHAMBERS
ARE RESIN MOVEMENT CONTROL
AREAS FOR THE FOR THE
POSITIVE AND COMPLETE
REMOVAL OF VOLATILE ORGANIC
COMPOUNDS FROM A GIVEN
FLOW OF CONTAMINATED AIR
V.O.C. CONTAMINATED AIR INLET
V.O.C. SATURATED RESIN HOPPER
RESIN CONTROL PIPING
MICROWAVE LAUNCHER CONNECTION
WAVEGUIDE
RESIN REGEN CHAMBER
RESIN CONTROL PIPING
RECOVERED V.O.C. TAKEOFF PIPING
ETHYLENE GLYCOL PUMP &
FLOW CONTROL SOLENOID SYSTEM
PRIMARY CONDENSER
#1 V.O.C. PUMP
SECONDARY CONDENSER
#2 V.O.C. PUMP
FENIX SYSTEMS LTD.
V.O.C. RECOVERY SYSTEM
SCHEMATIC / ASSEMBLY
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Product Information

DOWEX OPTIPORE V502

Polymeric adsorbent for removal of organics from air streams.

Dow has commercialized a new product for capturing volatile organic compounds (VOC) and hazardous air pollutants (HAP) from air. Designated as DOWEX* OPTIPORE* V502 polymeric adsorbent, this product was previously referred to as XUS 43502.01 while it was under development. The new adsorbent is a larger, 1.5 mm diameter, spherical bead material, designed to give lower pressure drop in vapor phase applications while retaining all the other attributes of the smaller particle size adsorbent, DOWEX OPTIPORE V493. Most other physical and chemical properties of V502, including equilibrium adsorption properties, are identical to those of DOWEX OPTIPORE V493.

DOWEX OPTIPORE V502 polymeric adsorbent is available in dry form, ready to use for most applications. Since DOWEX OPTIPORE V502 is a powerful adsorbent, it may adsorb odors and solvents during transportation and storage. The adsorbent can be precycled through a regeneration cycle prior to use to remove these materials. Table 1 lists typical properties for the adsorbent.

Figure 1 shows a pressure drop curve for DOWEX OPTIPORE V502 adsorbent as a function of air velocity downflow through a packed bed. For upflow applications, DOWEX OPTIPORE V502 adsorbent will begin to fluidize at an air velocity of 40 to 60 ft/min, depending on the bed depth.

Figure 2 shows a typical breakthrough curve obtained with DOWEX OPTIPORE V502 adsorbent in a vapor phase application. The figure plots the concentration of trichloroethylene in the column effluent divided by the feed concentration against bed volumes of air treated. The steepness of the breakthrough curve attests to the excellent kinetic performance of the product.

Catalytic Activity

In contrast to activated carbon, DOWEX OPTIPORE V502 adsorbent can be used to adsorb reactive solvents without catalyzing their decomposition. Reactive solvents such as acetone, methylethyl ketone, cyclohexanone and styrene have been adsorbed and desorbed without measurable change in composition. With most activated carbons, however, measurable solvent degradation occurs. In extreme cases, solvent degradation on carbon beds can lead to an uncontrollable exotherm and a subsequent bed fire. The lack of catalytic decomposition when using DOWEX OPTIPORE V502 adsorbent may be attributed to its extremely low mineral ash content.

Figure 1. Air Pressure Drop

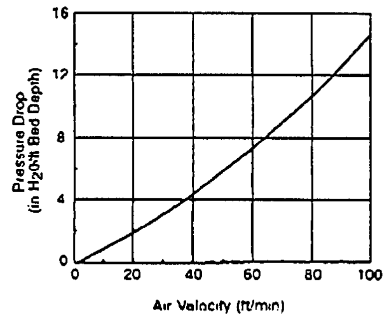


Figure 2. Breakthrough Curve for Trichloroethylene

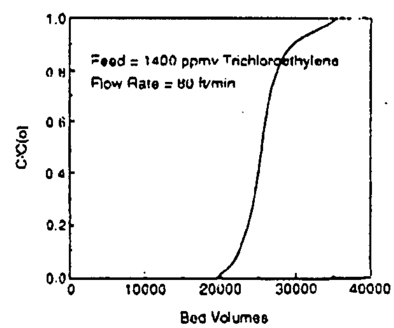


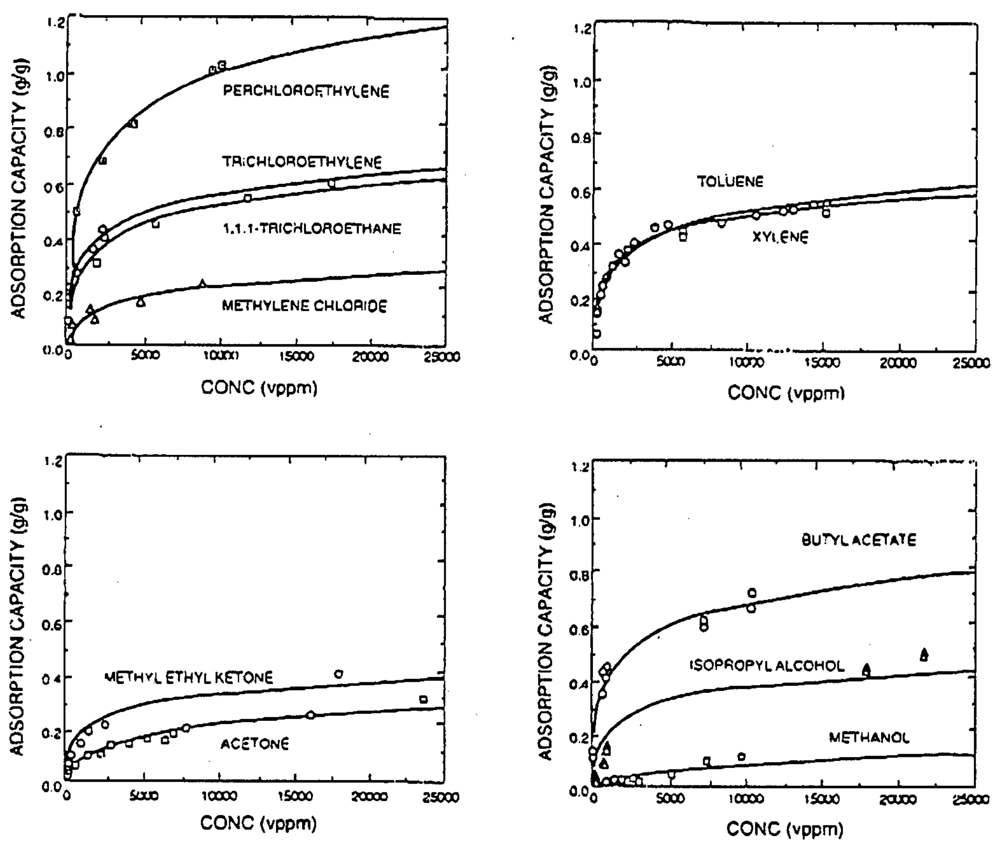
Table 1. Typical Physical and Chemical Properties of DOWEX OPTIPORE V502 Adsorbent.

DOWEX OPTIPORE V502	
Matrix Structure	Macroporous Styrenic Polymer
Physical Form	Orange to Brown Spheres
Particle Size (mm)	1.5
Moisture Content	<5%
BET Surface Area (m^2/g)	1080
Total Porosity (cc/g)	0.94
Average Pore Diameter (Å)	34
Apparent Density (g/cc)	0.4
Ash Content (%)	<0.01
Crush Strength (g/bead)	>1000

These properties are typical of the product and should not be confused with nor regarded as specifications.

DOWEX Ion Exchange Resins
For more information about DOWEX resins call Dow Liquid Separations.
North America 1-800-447-4369
Latin America ....(+55) 11-546-9348
Europe ....(+49) 7227-91-0
Japan ....(+81) 3-5460-2100
Pacific ....(+852) 2879-7261

Vapor Phase Adsorption Isotherms for DOWEX OPTIPORE V502 Adsorbent



Form No. 177-01508-595QRP

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